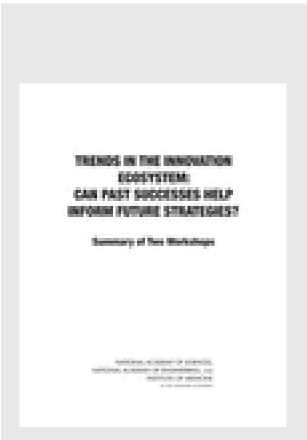


# Trends in the Innovation Ecosystem: Can Past Successes Help Inform Future Strategies? Summary of Two Workshops

**DETAILS**

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Committee on Science, Engineering, and Public Policy
Policy and Global Affairs

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NATIONAL ACADEMY OF ENGINEERING, AND
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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: Michael G. Borrus, X/Seed Capital Management; Brian Darmody, University of Maryland; James D. Plummer, Stanford University; Leon Sandler, Massachusetts Institute of Technology; William J. Spencer, SEMATECH (retired); and Eli Yablonovitch, University of California, Berkeley.

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 rapporteurs and the institution.

# Contents

# 1

# Introduction

Innovation has long been a contributor to American economic and societal progress, evident in a more than sevenfold increase in per capita income since the 19th century, an additional three decades of average lifespan, a revolution in the way we communicate and share information, and the country's position as the strongest military power in the world.[1] Without its historical leadership in innovation, the United States would be a very different country than it is today.

Yet agreement on what innovation entails or how it can be encouraged and facilitated is hard to find. Innovation often involves scientific and engineering research, and both universities and industry have essential roles to play. What happens at the intersection of these activities and institutions determines how productive the innovation ecosystem will be. But this system is in a constant state of evolution, driven by such forces as the variable pace of science and engineering, unexpected interactions among disciplines, restructuring of industry in a global economy, and the changing role of universities. If the innovation ecosystem is to thrive, it is essential to understand and adapt to these powerful external forces.

The Committee on Science, Engineering, and Public Policy (COSEPUP) of the National Academy of Sciences, National Academy of Engineering, and Institute of Medicine decided to host a pair of workshops entitled *Trends in the Innovation Ecosystem: Can Past Successes Help Inform Future Strategies?* to discuss the challenges involved in innovation pathways. Both workshops focused on the interactions between research universities and industry and the concept of innovation as a "culture" as opposed to an operational method. With the intent of stimulating conversation both during and after the workshops, the planning committee brought together representatives of many of the facets of university-industry interface. Recognizing that the views expressed were not exhaustive, the goal was to gain a better understanding of what key factors contributed to successful innovations in the past, how today's environment might necessitate changes in strategy, and

[1] *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Future* (Washington, DC: The National Academies Press, 2006).

[2] A list of the speakers from the workshops can be found in Appendix B.

[3] According to the Merriam-Webster dictionary culture is "the integrated pattern of human

what changes are likely to occur in the future in the context of a global innovation ecosystem.

On February 26, 2013, the first workshop brought together the members of COSEPUP and nine distinguished speakers from industry, academia, and finance at PARC at Xerox in Palo Alto, CA, to discuss obstacles to university-based innovation, and ways of overcoming those obstacles, focusing on the university side of the interface with industry in America. On May 20, 2013, COSEPUP held a second workshop in Washington, DC, which focused solely on research parks and was composed of two panels of experts on the structure and function of research parks.[2]

The speakers repeatedly highlighted the concept of culture as key to all aspects of innovation.[3] Different sectors and technologies have variations in culture that influence everything from how patents are valued to the time it takes to develop a market-ready product. The culture of universities and the role they play can dramatically influence the innovation ecosystem of a region. At the meeting in California, many of the academic participants actually "straddled" the two worlds of academia and industry, and discussed the difficulties they face in trying to start new companies while maintaining their academic careers. Research parks must be carefully tuned to the cultural needs of the people and industries using their resources to be successful.

But many observers have expressed concern that innovation in the United States is faltering as many centralized industrial research laboratories have disappeared and as the manufacturing sector has contracted. At the conclusion of the two workshops, questions still remained as to how best to move forward (see Box 1-1).

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[2] A list of the speakers from the workshops can be found in Appendix B.

[3] According to the Merriam-Webster dictionary culture is "the integrated pattern of human knowledge, belief, and behavior that depends upon the capacity for learning and transmitting knowledge to succeeding generations."

**Box 1-1**
**Questions to Answer**

- Is innovation getting harder?
- Is there a need to reexamine the intellectual property arrangement for basic research results?
- How should the national benefits of private sector enterprises be defined?
- How can the benefits of innovation in a region or country be retained?
- Is it feasible or desirable for the United States to mirror other countries' policies on subsidizing industries through direct financial support or regulatory collaboration?
- How will new immigration policies affect high-skill labor markets and the innovation ecosystem?
- What is the appropriate role of federal and state regulations and funding?

This summary of the presentations and discussions from the workshops organizes the discussion thematically. Chapter 2 examines the general principles that underlie university-based innovation, including the importance of people, culture, and experience as discussed during the February workshop. Chapter 3 considers the differences among industrial sectors and among technologies to explore the factors that contribute to successful innovation. Chapter 4 looks specifically at the roles of universities in preparing students, transferring technology to industry, and enabling faculty members to engage in entrepreneurial activities. Chapter 5 discusses the role of research parks, the variation that exists in their structures, and the importance of localization and adaptability to parks specifically and innovation in general. Chapter 6 asks how public policies in such areas as regulation, taxation, research funding, and immigration could reinvigorate university-based innovation in the United States.

The report has been prepared by the workshop rapporteurs as a factual summary of what occurred at the workshops. The planning committee's role was limited to planning and convening the workshops. The views contained in the report are those of individual workshop participants and do not necessarily represent the views of all workshop participants, the planning committee, or the National Research Council.

# 2

# The Elements of Success

Many things must come together for innovation to succeed. During the two workshops hosted by the Committee on Science, Engineering, and Public Policy (COSEPUP), participants identified a few general themes multiple times (see Box 2-1).

**Box 2-1**
**Major Themes of Workshop Speakers**

- The knowledge and experience of individuals are the primary drivers of innovation.
- Science and technology expertise alone is not enough to ensure innovation; the skills of finance, business development, production, and management are useful.
- Innovation is stimulated by the movement and interaction of individuals from different sectors.
- The culture of a region and its institutions shapes the nature of these interactions.
- Openness to new ideas and a tolerance for failure are important.
- Culture is not easily changed, and creating clones of Silicon Valley might be the wrong strategy.
- Innovation is a contact sport and might be facilitated by a concentration of talent that increases the rate of interaction.
- General principles do not explain everything. Significant differences exist among institutions, regions, industries, and sectors.

Various speakers emphasized the importance of three critical factors: culture, people, and experience. The remainder of this chapter provides some highlights on these topics from the speakers at the California workshop.

## THE IMPORTANCE OF PEOPLE

Innovation is almost never an isolated occurrence. It tends to take place in an environment characterized by personal interactions, an entrepreneurial spirit, a variety of supporting institutions, adequate funding, and the vibrant development and exchange of ideas. Many analysts have used the metaphor of an ecosystem to describe such an environment, but the speakers at the California workshop tended to speak instead of a culture that fosters innovation.

Culture includes the expectations that people hold about how they and others will interact. For example, David Mowery, Milton W. Terrill Professor of Business at the Walter A. Haas School of Business, University of California, Berkeley, observed that the U.S. university system is unusual among industrialized countries in having a long history of interaction with industry. Furthermore, the flow of ideas and people occurs in two directions, not just one. Many of the innovative activities within universities rely on input from industry of both ideas and people. As an example, Mowery cited work done at Berkeley on a major component of the Unix operating system that relied on people from Bell Laboratories spending time on the campus. Similarly, Mowery reported that a vigorous scientific instrument complex has grown up around the University of California, Santa Barbara, because of the two-way flow of individuals and ideas back and forth between the university and businesses. Such interactions have been very rare in western Europe or Japan, though they may become more common in China as the university sector there develops.

An aspect of the ecosystem and of the culture in Silicon Valley that was examined extensively at the workshop is the venture capital industry. Venture capital grew from a tiny industry in the 1960s to a peak in the year 2000, after which it has undergone major changes. Prior to the 1960s, entrepreneurs tended to approach individuals, families, and privately owned companies with an interest in science and technology as a source of funds for innovation. Since then, they have more frequently turned to venture capitalists for early-stage investments. Many venture capital firms cluster around Stanford and the other universities in the Bay Area, where they have quick access to the faculty members and students who have ideas to commercialize. These venture capitalists are themselves intermediaries between limited partners who provide the capital and the innovators who use that capital to create, develop, produce, and market new products and services.

Physical proximity between venture capitalists and entrepreneurs is often critical. Steven Quake, Professor of Bioengineering at Stanford and an investigator with the Howard Hughes Medical Institute, explained that one of the companies he helped found grew from a boat ride with a college friend who wanted to leave his position in a large company and become an entrepreneur. Though they had great difficulty raising money because of a slump in venture capital funding for biotechnology, they eventually were connected with an angel investor by the technology transfer office at the California Institute of Technology. That initial investment led to future investments and, as the venture capital market for biotechnology recovered, "the VCs were calling us," said Quake.

However, other companies that Quake helped found have different roots. In one case, venture capitalists who had read his scientific papers contacted him about the ideas they contained. The investors in this case brought in a chief executive officer to provide expertise in running the company. In another case, a large company funded a startup to the point where a decision could be made about whether or not to acquire the company, which is becoming a popular model in the pharmaceutical industry, according to Quake.

Since the bursting of the dot-com bubble in the year 2000, the venture capital industry has gone in new directions, according to Michael Borrus, Founding/Managing General Partner at X/Seed Capital Management. For example, venture capitalists have made poor returns on investments in hardware since then, and they have reduced their investments accordingly. As a result, a crunch has emerged in the funding of hardware development, raising the question of how America can maintain its leadership position in hardware when other governments are willing to nurture their hardware industries. (Chapter 4 looks at shifts in investment priorities in greater detail.)

Venture capital also has reacted to changes in the distribution of success. For example, John Hennessy, the President of Stanford University, pointed out that the information technology industry has become more bimodal in its success rates, with a smaller percentage of companies succeeding. In the past, perhaps 70 percent of the spinoffs from Stanford in the information technology sector got to the breakeven point, he said. Today the percentage is much smaller -- perhaps 30 percent. Investors seem to be searching for the occasional company that produces very large returns, even if small investments are lost in the majority of startups. "If you get a Google or Facebook, you pay off the last four funds with one company," Hennessy said. He also noted that, as venture capital firms have matured, an angel investor network has developed in Silicon Valley that devotes time, energy, and capital to small companies.

Borrus described his small venture capital company as an example of some of the trends affecting the industry. His first investment fund was divided roughly equally among three sectors: the life sciences; energy and resources; and information technology, which includes both hardware and predictive analytics (i.e., what has come to be known as "big data"). A more recent and larger fund is devoted almost exclusively to information technology, despite Borrus's interest in technology across the board. But ecosystems that support the commercialization of innovations that require long timeframes and large amounts of capital in areas such as the life sciences and energy are in "disarray," he said.

X/Seed is typically the first institutional investor in the technologies it supports, though other funds and angel investors also may be involved. But many of the companies in which it invests eventually need larger pools of follow-on capital from larger venture funds or other sources. In some fields, including energy and the life sciences, sources of follow-on capital have largely dried up. "There aren't very many life science venture funds that have raised capital in the last 18 months," Borrus said. And without follow-on investors, the company in which he invests can become stranded.

The venture capital industry is based on the idea of profiting from risk. But it also points to one more aspect of culture that was discussed by several participants at the workshop: the willingness to accept failure. In many other countries, acceptance of failure is much more limited, which constrains the ability to invest in risky ideas.

## THE IMPORTANCE OF CULTURE

Technology transfer is a misnomer, said Hennessy. Technologies generally are not transferred from one institution to another, such as from a university to a company. Rather, people are transferred, and those people bring ideas and experience with them or the ability to innovate if provided with the opportunity to do so. For example, some of the greatest success stories of Silicon Valley involved the transfer of people from Stanford, said Hennessy, including William Hewlitt and David Packard (the founders of Hewlitt-Packard), Jerry Yang and David Filo (the founders of Yahoo!), and Larry Page and Sergey Brin (the founders of Google). Other successful innovators who have contributed to the success of Silicon Valley have come from the University of California, Berkeley, from the University of California, San Francisco, and from companies and other institutions throughout the Bay Area.

The transfer of technology often takes place through the creation of small startup companies that attract talented and experienced innovators. Small companies can turn an invention into a working prototype, build customer interest, and take a technology to scale or be acquired by a larger company that can do so, Hennessy observed. In that way, they function as a bridge between academia and industry. Transferring technology directly to a large company tends to be much more difficult. When a new product starts generating profits for a large company, it may change the bottom line for that company very little. Also, a fundamentally new technology may threaten an existing product line or business. Large companies even may kill an internal development project that threatens an existing business only to see that business undermined by a small startup company anyway.

## THE IMPORTANCE OF EXPERIENCE

A final element of success that workshop participants discussed is experience. Among the great advantages of Silicon Valley are the number and experience of its entrepreneurs, said Borrus. For more than 40 years, entrepreneurs in Silicon Valley have been learning how to build high-growth companies, often with venture-backed funding. They have had experience not only with university research but with research and development in companies, from which many innovative ideas emerge. People know how to start and run small businesses, which is a very different experience than being part of a large company. Many people have connections with both universities and with industry, and these dual affiliations are a prominent part of the Silicon Valley culture that can be difficult to replicate elsewhere. People also are willing to move among institutions and sectors, thereby bringing their experience to new endeavors.

University faculty may be smart and creative, Hennessy said, but many have no idea of what it means to deliver a product to the world, how to set up and run a company, how to handle sales and marketing, and so on. Engineers with a new invention tend to see the glass as half full, but they often need help convincing potential investors that the glass is not in fact half empty, Yi Cui, Associate Professor in the Department of Materials Science and Engineering at Stanford University, agreed. They need to learn management skills or hire people with those skills to be successful. In such cases, a small company may need to learn how to work with a large company, especially in areas such as energy that require large investments. That is one key to Silicon's valley success, said Hennessy -- each successful company creates a group of skilled and experienced people who then can train the next generation of successful entrepreneurs.

As Mowery pointed out, managerial talent may be less mobile geographically than capital or labor. "Part of what you develop as a venture capitalist is a good Rolodex of people within 50 miles, and that talent is a very important part of what VCs are bringing to these new firms, especially new firms founded by relatively inexperienced entrepreneurs in their first spinouts." Small companies may even move from other countries to take advantage of the managerial expertise in the United States.

# 3

# Differences Among Technologies

A prominent topic of discussion at the workshop in Silicon Valley was the differences among technological fields. Frequently discussed points are highlighted in Box 3-1.

**Box 3-1**
**Differences across Sectors and Technologies**

- Innovation can be understood better when in its particular context. Very few generalizations can be made that apply equally to software, computer hardware, medical devices, pharmaceuticals, energy production equipment, etc.
- The time cycle of bringing a product to market benefits some areas of innovation and impairs others.
- One common weakness of universities is a reluctance to make hard decisions about shutting down unproductive projects.
- There is existing and increasing concern about the biomedical sector.
- Regulation has a significant influence on innovation.
- Venture capital undergoes dramatic fluctuations by field.
- Open research – particularly at the precompetitive level – has been valuable and generally preferable for some sectors.

Innovators in information technology, biotechnology, and energy technologies, which were the three sectors discussed in detail at the California workshop, face very different circumstances with regard to such factors as financial demands, time to product, and intellectual property protection. These differences call for nuanced policy approaches, as described in the final chapter of this workshop summary.

## INFORMATION TECHNOLOGIES

David Hodges, professor of electrical engineering and computer sciences at the University of California, Berkeley, described two university-based information technology projects as examples of innovations that have produced large returns in the past. The first involves a program called SPICE, for Simulation Program with Integrated Circuit Emphasis, which was inaugurated by Hodges' doctoral adviser Donald Pederson in the 1970s. SPICE is an electronic circuit simulator that is used to design circuits and examine their behavior. "It was a huge success and had a high impact," said Hodges, and 40 years later it is still the preferred tool for its purpose.

The project was based on complete openness, said Hodges. It had no patents or non-disclosure agreements, and its copyright agreement said that others were free to use the program so long as they acknowledged its source. As a result of the project's openness, industry initially was not much interested in SPICE, but the program was adopted by Hewlett-Packard and Tektronix for use in the design of chips for their own instruments. Faculty members, students, interns, and company personnel participated in the project, and they brought their experience with the program to subsequent endeavors in academia, industry, and government.

The second technology Hodges described was Reduced Instruction Set Computing (RISC), a term coined by David Patterson at Berkeley, who was one of the developers of the technology. This technology, too, was developed on an open basis, with the developers at Berkeley inviting representatives of computer companies to come talk about the technology so long as the conversations were not secret or proprietary. According to Hodges, participants at those meetings would say, "Wow, I learned so much from those other guys' questions." Today, cell phones and many other devices have RISC chips, and many successful companies have emerged from the development of the technology.

"I'm advocating for the model where you say, 'Let's have the maximum free exchange of ideas,'" Hodges concluded. "There are lots of ways for innovation to occur, and universities are in a unique position to create [an open] environment. . . .You would have a far inferior research environment if you shut down the free exchange of ideas."

## BIOTECHNOLOGY AND MEDICAL TECHNOLOGIES

In contrast to the information technology sector, which remains a hotbed of innovation, the innovation model in the life sciences is "deeply broken," according to Hennessy. Information technologies are generally well along the path to commercialization once a company is spun off to develop that technology. The question then becomes whether the company can build a team to get the technology to market while the window is open for that technology. (Another question is whether, as Hennessy put it, the "dogs will eat the dogfood" ─in other words, will the technology be used by the people at whom it is aimed?) With the life sciences, however, many innovations have not yet been developed to the point that they work reliably when startup companies are formed. Both Edward Penhoet, co-founder and former Chief Executive Officer of Chiron, and William Rutter, co-founder of Chiron and professor emeritus at the University of California, San Francisco, pointed out that as a result, the development those companies are doing is too often at a fundamental level. Startup companies need to focus on getting a product out the door so they can get a second product out the door, Hennessy said. They cannot afford to devote their resources to research.

Development also tends to be much more expensive and take longer in the life sciences than in other fields. The money needed to fund a startup information technology company can be barely enough to rent laboratory space for a biotechnology company. And the development of a product can take longer than venture capitalists or other sources of support may be willing to wait.

Several participants pointed out that because of these obstacles to innovation, the biotechnology and medical technology fields have been emphasizing short-term incremental improvements in products rather than major innovations. Yet major innovations are needed to support the investments required to develop products in these field. In addition, medical technologies suffer because the markets for such products are smaller than for pharmaceuticals but the costs and time needed to bring such products to market also are increasing.

Great diversity also exists within individual fields of technology, and this diversity sometimes can be leveraged to foster innovation. For example, Rutter described his involvement in Synergenics, which essentially consists of eight different, linked biotechnology companies that are pursuing a variety of long-term and short-term projects. Each of the companies is independent and has its own intellectual property, but they also engage in a great deal of interchange so that they can benefit from each other. Facilities and even personnel can be shared while executive overhead is minimized. Having more than one company within an overarching structure also makes it easier both to start a new company and to shut down an existing one.

## ENERGY TECHNOLOGIES

A technological sector with different attributes on many of these measures than either information technologies or biotechnologies is energy technology—and specifically battery technology was discussed at the workshop.

When Yi Cui began doing research on batteries in 2005, interest in the topic was at a low ebb. But Cui perceived a need for better batteries, and he believed that he could bring his expertise in nanomaterials to problems in the battery field. For his first few years at Stanford, he had trouble interesting others in battery technology and getting grants for research on energy storage. But starting in 2008, attitudes began to change, and batteries became a hot technology. Though his university colleagues advised Cui to get tenure first, he became interested in commercializing the technologies he was researching. He began talking with venture capitalists and eventually co-founded the company Amprius, which has been working to build batteries that use nanowires to yield greatly expanded capacity and recharging capabilities.

Battery technologies face some of the same problems as technologies in the life sciences, Cui observed. For example, most venture capitalists would like to see a return within four years or less, if possible. But many battery technologies take substantially longer than that amount of time to develop, which increases the difficulty of securing venture capital or other sources of support.

Battery technologies also can be expensive to develop, which can lead innovators to look for ways to stretch available funding. For example, Cui pointed out that the money that it takes to support a startup company in the United States for two days can support a comparable company in China for a month. He also pointed out that refusing to make these investments can be immensely shortsighted because of the huge returns some innovations can produce. As an example, he pointed to a study released in 2012 estimating that companies formed by Stanford entrepreneurs generate world revenues of $2.7 trillion annually and have created 5.4 million jobs since the 1930s.[4]

## IS INNOVATION GETTING HARDER?

Workshop participants also discussed the intriguing debate currently under way about whether innovation is becoming more difficult. Mowery pointed out that a body of primarily economic research contends that it is. Inventors are producing their most important contributions to knowledge at an advancing age across different fields of research, which points to the increasing need to amass a large body of knowledge and experience to make a significant innovative contribution. The number of authors on research papers and contributors to patents also is growing, suggesting that innovation requires larger and more complex undertakings than in the past. Meanwhile, key indicators, such as the number of new drugs or new chemical entities being produced, are trending downward. Even Moore's law—that the power of computer chips doubles approximately every eighteen months—is running up against physical limitations, and the pharmaceutical industry is beginning to speak of Eroom's law (Moore spelled backwards), given that the absolute number of innovations and return on investments in that industry appear to be declining over time.

[4] Charles E. Eesley and William F. Miller. 2012. *Stanford University's Economic Impact via Innovation and Entrepreneurship.* Available at http://engineering.stanford.edu/sites/default/files/Stanford_Alumni_Innovation_Survey_Report_102412_1.pdf.

One important aspect of innovation is that economists and policy makers cannot measure the output, Mowery said. They can only measure the inputs—in terms of funding or investigators, for example—and try to infer an output. But influential economists have been arguing that a given set of inputs will produce fewer outputs in the future (though Mowery said he had "no idea how they know this"). This issue might be a good topic for COSEPUP or some other group at the National Academies to investigate, he suggested.

Workshop participants also discussed other fundamental and long-term impacts of technology. One possibility is that new technologies are displacing employment in the United States, although this concern also has surfaced periodically in the past (about every 25 years, Mowery noted). Treating unemployment at an aggregate level also glosses over the underlying dynamics. For example, Mowery pointed out that additive manufacturing—or as it is sometimes called, 3D printing—could create a demand for workers with skills that U.S. schools are not producing. In addition, private sector employment has recovered from the recession that started in 2008 at about the same pace as after previous recessions, but public sector employment has lagged.

Technology also may be having an impact on the growing economic inequality in industrialized countries, Mowery said. Again, a workshop on the links between innovation, unemployment, and inequality could explore how these factors are conceptualized, measured, and interconnected.

# 4

# The Roles of Universities

Universities are important sources of many of the new ideas in science and technology that contribute to innovation in the United States. By producing new knowledge and exposing students to that knowledge, they not only generate new ideas but prepare knowledgeable, inventive, and motivated graduates who can carry those ideas into businesses, nongovernmental organizations, and governments. In addition, faculty members sometimes play a direct role by consulting with existing companies or even starting their own companies. A majority of the first workshop was devoted to considering the role of universities in the innovation ecosystem. Some of the common themes are cited in Box 4-1.

**Box 4-1**
**The Role of the University**

- The culture of a university influences its success in producing innovation and can influence the culture of a region.
- A university does not merely prepare young people for the wide variety of roles in an innovative economy; its higher mission is to "discover and invent the future."
- The technology transfer policies of universities may be in need of rigorous review and assessment.
- Universities might benefit from examining the rules governing the amount of time faculty can devote to outside activity.
- Faculty members and students can have conflicts of interest and conflicts of commitment that need to be understood and properly managed.

## THE PREPARATION OF STUDENTS

The most important product of universities, said several workshop participants, is educated students. These students include not just the founders of new companies but the employees and customers of those companies. The first few hires for a startup are critical, said Hennessy, but the next one hundred or one thousand people a company hires are also important for its success.

Universities should not be farm teams for industry, Hennessy said; they should not be engaged in designing the next product for a company's line. Instead, they should seek the discontinuous innovations that create or transform an industry while teaching their students how to think critically and creatively. The job of a university is to "discover and invent the future," Hennessy said—in part through research, in part through education, and in part through active efforts to move university-derived ideas into industry.

Investments by governments at all levels are essential if universities are to fulfill these missions. Eli Yablonovitch, director of the NSF Center for Energy Efficient Electronics Science at Berkeley, once calculated how much the government had invested in his education and concluded that the total was close to a million dollars. Furthermore, even after graduating, he had access to good jobs and good organizations where he was able to develop his expertise. "The human capital aspect is gigantic," he said.

## THE TRANSFER OF TECHNOLOGY TO INDUSTRY

Many universities have created offices to foster the transfer and licensing of technologies developed by faculty members and students to industry. These offices can establish beneficial relationships with individuals and organizations outside universities. As Borrus said, "If you build a relationship there, it's like any other walk of life, you can get things done."

Several speakers at the workshop also discussed problems with these offices and ways in which they could function more effectively. Mowery pointed out that technology transfer offices often have competing mandates. The university president sets one set of goals, licensing officers are evaluated on a different set of criteria, and state legislators mandate yet another set of objectives. Many participants pointed out that this reflects the fact that universities have multiple objectives that they want to achieve through technology licensing, including regional development, revenue generation, and recruiting and retaining faculty (for example, by supporting faculty spinoff companies), and these objectives are rarely prioritized. At the same time, technology licensing offices often are evaluated solely by the amount of revenue they generate, which creates the wrong incentives and can disrupt the academic environment and culture, thus suppressing interactions with industry rather than fostering them.

The revenue generated from technology licensing tends to be featured in publications from a university and talks by administrators, but almost all the data on licensing revenues consist of gross revenues. The net returns are much smaller after operating expenses and other liabilities are subtracted, said Mowery. With a few exceptions, such as Stanford, the net licensing revenues are much smaller than the amount of industry-sponsored research at a university.

This creates a tension between using licensing policy to maximize revenue and using licensing policy to develop broader relationships with industry.

Mowery pointed toward "an astonishing lack of experimentation" by universities of different ways of organizing their relationships with industry. As an example of such experimentation, he pointed to the University of California system, where faculty members have the option of not working with the technology licensing office. Instead of patenting an invention, they can put it in the public domain and seek benefits from exchanges with people who want to discuss an innovation and make a product based on that idea. This does not work in all fields of technology, and administrators may lament potential losses of revenue, but in some areas it is a valuable alternative to technology licensing.

Many universities have tried to emulate the licensing successes of Stanford when in fact they are very different kinds of institutions, said Mowery. The heterogeneity of U.S. higher education has always been one of its strengths and creates opportunities for experimentation. In addition, collaboration among different types of colleges and universities offers the potential to increase benefits and reduce costs.

Even at universities that have had great successes with technology licensing, the returns can be deceptive. The current chairman of COSEPUP, Richard Zare, the Marguerite Blake Wilbur Professor in Natural Science at Stanford, said that he had looked at the greatest returns to Stanford from licensing. The greatest single return came from patents that Stanley Cohen and Herbert Boyer were granted on the recombinant DNA techniques they pioneered. The second biggest return came from the School of Music for the invention of technologies used in the Yamaha synthesizer. The third largest return was for licensing of the Stanford logo.

Zare insisted that Stanford graduates return much more to the university than does its licensing. "It's not Hewlett-Packard but Hewlett and Packard individually and their families who have given money back to Stanford." As Hennessy said, the philanthropy from Hewlett and Packard to Stanford dwarfed any licensing fee that could have been charged for the discoveries they used to start their company.

Some workshop participants made the case that technology licensing offices can be counterproductive if they cause negotiations to be so complex that agreements are scuttled. They also pointed to the negative consequences of a belief widespread among state legislators that licensing offices could produce abundant resources for universities, which then could displace government funding. Even senior university officials and technology licensing officers sometimes have a "somewhat naïve view" that all areas of technology have the potential to create successes that in the past have occurred in just a few particular circumstances. In fact, the objectives of technology licensing offices are much broader. These offices can forge connections with industry, help faculty members move their ideas beyond the walls of the university, and support regional and national economies.

Participants also mentioned other ways some universities accelerate the transfer of technology to industry where commercially promising ideas or technologies can be developed, either within academic or commercial settings, such as incubators, accelerators, or proof-of-concept centers. These institutions can have different characteristics depending on the technology they are fostering. For example, the biotechnology sector requires expensive access to laboratories, equipment, and staff, while the information technology sector may require much smaller investments. Hennessy described one approach Stanford has pursued to support student-driven innovations for three to six months to see if they can be developed to the point where they would attract commercial interest or the interest of a venture capital firm or angel investor. It remains an interesting educational experience for the students with a very minimal investment, Hennessy observed. For example, he mentioned a group of students who were working on a way for students to pay each other money using their phones. The students got money to spend three months working on the project, and they lived in a house together and spent 12 hours a day working to see what the technology could do. It cost $5,000 to support the students, and they had an educational experience that resulted in a potential business opportunity.

The biggest problem with incubators, according to Hennessy, is that they need to be shut down if they are not producing results, and shutting them down can be difficult. "You give them a hard deadline and say, go out and get funding by this deadline or you are out." The history of incubators at universities is not promising, because they often require that university staff members shut down projects led by faculty members. "You could do it and make it work, but it would take tough love," said Hennessy. One possibility suggested by Zare would be to have the industrial part of an incubator report directly to the administration of a university and be judged over a five-year time frame rather than on a year-to-year basis. Another possibility, suggested at the second workshop on research parks, would be for an industrial park to be part of a university-government entity that could take equity in early start-up companies.

## THE ROLES OF FACULTY MEMBERS

Faculty members transfer technology directly to industry when they help start new companies or consult with existing companies.[5] For example, Yablonovitch described the four companies he helped start beginning in 2000. Yablonovitch remained a professor at Berkeley even as he was forming his companies. He said that his job was to conceive of a valid business idea and then hire the technical team. The team ran the company, while he served on the

[5] It should be noted that, although the participants did not discuss it explicitly, throughout their discussions they implicitly acknowledged that the freedom given to individual faculty members to explore, coupled with a culture in which failure is at least occasionally acceptable, is a striking component of the U.S. research and innovation system.

boards of the company. This approach has worked well in the past, he said, though it may not be the right model for all sectors.

Yablonovitch said that he has always favored business ideas that have a strong scientific component. This can be problematic, he admitted, in that society wants its needs to be fulfilled. Researchers, in contrast, are often interested in ideas that are different, elegant, or clever, but “society didn’t ask for that. There’s a bit of conflict there, and sometimes you end up being too far ahead or not focusing on basics, where there is money to be made just doing the basics.”

His first company, Ethertronics, was established to pursue new designs for cell phone antennas. Initially the company secured a patent on a promising design, but the patent turned out to be less useful than anticipated. For four years the company worked on new ideas with few returns until a “deeper understanding of Maxwell’s equations” led to a radically new antenna concept that increased efficiencies from approximately 33 percent to 50 percent. At the time of the workshop, the company had shipped 700 million antennas, most of which are still in operating phones, meaning that about one-tenth of humanity is using the technology. But the company has not been as profitable as might be expected, because it has relatively few customers, and the customers are able to dictate the price they will pay for the antennas. “It’s certainly a technical success and has impacted society, but it hasn’t made that much money.”

Luxtera, which is a pioneering company in silicon photonics, originated when a venture capitalist came to Yablonovitch and expressed interest in starting a photonics company. Though Yablonovitch was worried that the technology was not yet developed enough for commercialization, he started the company and began developing a silicon chip that included optical components as well as semiconductor components. The initial product was a cable that converts electronic signals to photonic signals, which travel along a fiber optic strand until they are converted back into electronic signals on the other end of the cable. The cable is much faster than a USB cable and has attracted the attention of people who run supercomputers and large data centers.

A major issue in this case, said Yablonovitch, is that many companies have become involved in this area, and each has taken a slightly different approach to the technology. At this point it is difficult to say which approach is best. Luxtera therefore could become known as the company that pioneered the technology, but another company might end up making more money from the technology.

A third company, developed with a mathematician at the University of California, Los Angeles, creates the patterns for photolithography to manufacture sub-wavelength features on silicon wafers. These patterns are not at all intuitive, because when light shines through them it creates a quite different pattern on the substrate. The business model was therefore to provide the patterns to semiconductor manufacturers that wanted to build semiconductor chips. Furthermore, because the patterns are not unique, as typically happens with mathematical problems involving inverse transformations, the patterns can be engineered to be insensitive to errors in depth of field, easier to manufacture, and so on.

The technology was successful, and it ended up being particularly useful for chips that contain repetitive elements, such as memory chips. However, this company also had relatively few customers, which meant that it had relatively little power to set prices. Eventually, the part of the company making the inverse patterns was sold to another company.

Finally, Yablonovitch's fourth company, AltaDevices, has broken the world record for solar-cell efficiency, taking it from 25.1 percent to 28.8 percent efficiency. The technology is based on the idea that a solar cell achieves its highest efficiency when it emits a small amount of light, which was "very counterintuitive," said Yablonovitch. Today the cells are being used in applications like space satellites, and an inexpensive way of producing the cells could lead to a much broader range of applications.

However, solar cell technologies also have run into problems because of the large government subsidies that other countries, and especially China, have devoted to this area. Interest-free loans, production subsidies, and other governmental investments have driven the price of conventional solar cells down to a level where they cannot be profitably manufactured without subsidies. As a result, said Yablonovitch, "all the competing technologies are losing their shirts. . . . No matter how good your technology is, you can't deal with a heavily subsidized competitor." In addition, ill-advised overinvestment by U.S. venture capitalists in the first decade of the century have scared current investors away from the field.

Today, China is overproducing the world's needs for solar cells by a factor of two, said Yablonovitch, and the subsidies appear likely to continue for years. "Even if you have good technology and you are successful technically, the market conditions have changed." Other countries seem to be willing to make investments in the field even though they know they will lose money. But they hope eventually to gain a powerful market position. As a result, in the future innovators may need to go to Asia to secure investment funds, just as they once came to the venture capitalists clustered around Stanford to seek funding. And will the federal government continue to invest money in research if the companies based on that research end up going offshore, Yablonovitch asked. "These are very vexing issues for which I don't have answers."

Traditionally, faculty members have been allowed one day a week for work on outside projects. Workshop participants discussed whether these guidelines should be modified to give university innovators more time to work on commercializing an idea. However, Hennessy warned against 50-50 splits. It would be better for a professor to take a leave from the university to work on an outside project, possibly while spending a limited amount of time maintaining ties with a university. However, leaves typically have to be accompanied by a time limit, since otherwise they can drag on for technologies that are proving difficult or time consuming to develop. If people decide that they need to stay with a company once a time limit is reached, they can break their ties with the university, and if they are successful, they may be able to rejoin the faculty later. "I'm fairly flexible with respect to that," said Hennessy.

Mowery said that he is skeptical about efforts to use institutional resources to turn faculty into entrepreneurs. Faculty should certainty not be discouraged from engaging in innovation activities and should be supported when they do, but evaluating faculty on the basis of these activities is not a good idea, he said. An evaluation based on patents obtained, for example, would certainty generate more patenting, but "patenting is not necessarily a way of either supporting technology transfer or of reducing the operating expenses of a technology transfer office." Many faculty members would not be good industrial managers. In fact, access to outside managerial talent is an important contribution that venture capitalists bring to the interface. "Trying to fit faculty who may or may not be square into square boxes is very much to be avoided."

# 5

# The Role of Research Parks

Over the course of the discussions that occurred at the first workshop in February, many participants and COSEPUP members noted that it is important to consider regional and institutional cultures. Specifically, they observed that universities and private companies have very different cultures and that a major challenge is to understand and deal with the differences. One way to bridge the gap is to create intermediary institutions—research parks —that are a hybrid of university and company cultures.

To investigate these multifaceted enterprises further, COSEPUP determined that an additional, smaller set of discussions should be held in Washington, DC, with experts experienced in many aspects of research park creation, promotion, management, and utilization. This chapter focuses on the discussion from those panels, with some of the more frequently mentioned topics listed in Box 5-1.

**Box 5-1**
**The Role of the Research Parks**

- Research parks are important institutions for filling in some of the gaps between research institutions and industry.
- Research parks help regions turn their investment in education into good jobs and economic productivity.
- Significant variety exists among research parks.
- Research parks need external support.
- Formation of research parks has continued at rapid pace and has spread quickly internationally.
- Research parks are not necessary to develop research capacity. However, they can stimulate the economy by enhancing research capacity enough to support higher-value activities and attract business investment.
- Research parks benefit from evolving and responding to competition.
- Scale matters.

## THE CONNECTION BETWEEN PARTS OF THE SYSTEM

Research parks are numerous and vary in composition and operation. Charles Wessner, the associate director of Board on Science, Technology, and Economic Policy (STEP) at the National Academy of Sciences, quoted Professor Al Link's observation that "If you've seen one research park, you've seen one research park." Nevertheless, Wessner noted that during the more than 20 years STEP has been studying research parks a common mission has emerged: they help regions turn their investment in education into good jobs and economic productivity.

The first parks were created in the 1950s by universities that saw a need for a middle ground where researchers with commercially promising ideas could work with business and financial experts to develop ideas into products. Research parks have proliferated since. Universities have been the most prevalent sponsors, but national labs and state governments have also launched parks. Eileen Walker, the executive director of the Association of University Research Parks, explained that the growth in the number of parks has actually accelerated in the past decade, and parks have also become common in Europe and Asia. Worldwide, there are now over 460 research parks with a total of more than 380,000 employees.

Walker pointed to three primary objectives for research parks: to "create an environment that encourages innovation," "offer industry access for faculty and students," and "serve as a landing pad for industry recruitment." Each park, however, must adapt to local and regional strengths and goals.

The representatives of the parks who participated in the workshop provided ample evidence that this is true. On one end of the spectrum, John Hardin, the executive director of the North Carolina Board of Science and Technology, explained that Research Triangle Park has 170 companies with 40,000 employees. At the other extreme, Lewis Branscomb, co-founder of the Joint Institute for Laboratory Astrophysics (JILA), pointed out that JILA is actually a virtual organization with no employees. Instead, it provides a place where hundreds of researchers who work for the University of Colorado at Boulder or the National Institute of Standards and Technology can work side by side or together.

## TYPES OF RESEARCH PARKS

The significant variation among research parks was described by representatives from a number of the parks themselves.

Research Triangle Park (RTP), founded in 1959, was among the first and is perhaps the world's best known research park. Hardin told COSEPUP that it was a "highly ambitious 'big bet' that served as a catalyst for assembling and aligning the knowledge resources and business climate attributes to create opportunities for the people of North Carolina." Cited as one of the best gambles taken by a state, according to Hardin, it was intended to link Duke University in Durham, North Carolina State University in Raleigh, and the University of North Carolina at Chapel Hill, and utilize a local airport in an originally low-population, primarily farmland region. As Branscomb noted, while RTP might not be known for cutting edge innovations, its regional economic impact cannot be overstated.

Known primarily for its success in attracting large companies such as IBM, RTP has actually drawn a much more diverse clientele. Over 60 percent of RTP's 170 companies have fewer than 25 employees. The vast majority of companies (about 82 percent) are involved in scientific industries, with the preponderance of those in the life sciences.

Research parks in general work primarily with established companies, but some also include incubator programs designed to help entrepreneurs launch new companies. RTP, for example, has six start-up incubators, but this is a relatively small part of the operation. There are also SBIR and STTR matching grant programs across the state of North Carolina, as well as other, sector-specific networking and mentoring programs. Even with all of these supports in place, Hardin admitted that, for small new companies, "it is easier to fail than to succeed."

Indeed, in the past decade RTP has seen a slowdown in employment growth. As a state, North Carolina has seen a fall in per capita income as compared to the U.S. average. To address these concerns, the North Carolina

Department of Commerce is undertaking a revitalization effort for RTP, said Hardin. This plan—which involves development of support infrastructure like service industry and public transportation within RTP as well as changes to local zoning laws—highlighted the fact that research parks must provide both hard infrastructure of transportation and communications and soft infrastructure of education and cultural amenities.

The situation in Maryland is slightly different. "Research parks are where academic culture meets corporate culture," said Brian Darmody, the Associate Vice President for Research and Economic Development and the Director of Corporate Relations for University of Maryland (UMD) and the Special Assistant Vice Chancellor for Technology Development for the University System of Maryland, although he described his position as the "Director of University-Corporate Happiness." Because of the unique position of all the different players in and around the University of Maryland, Darmody stressed the opportunities research parks there provide to both entrepreneurs and local federal agencies.

One of the major functions of research parks that Darmody mentioned was helping universities overcome innovation barriers by explaining and navigating compliance regulations. He noted that entrepreneurs tend to be non-compliant people, which is why they are innovators. One example he gave was if a project needed classified research that must be done off campus: a research park could provide the space. In addition, to work with industry, university entrepreneurs must branch across departmental barriers because industry representatives want to work with only one office. This actually has a benefit for the research community on campus by "breaking down silos" that form between fields.

In addition to these standard industry-university relations, UMD research parks also provide and receive unique opportunities from the high density of local federal facilities. The University of Maryland has many nearby federal institutions, including National Oceanic and Atmospheric Administration's National Centers for Environmental Prediction, National Aeronautics and Space Administration (NASA)'s Goddard Space Flight Center, the Department of Defense funded Center for Advanced Study of Language, and the Food and Drug Administration (FDA)'s Center for Food Safety and Applied Nutrition.

One example of the symbiotic federal relationship that he pointed to was the FDA's international training program in food safety held at the research park. He explained that because of the global nature of the market, the best way to ensure food safety is to encourage other countries to adopt FDA standards via lab-based training. However, the federal nature of the FDA's lab restricts foreigners from attending the campus. The UMD Park provides a geographically proximal middle ground where the training can be done by FDA staff using the appropriate equipment, with the added benefit of stimulating the local economy through hotel and travel accommodations.

The interactions with the federal agencies are not one-way streets, and UMD has benefited from federal programs such as the National Science Foundation's Innovation Corps programs, which aim to move new ideas out of the lab and into practice.

Federal laboratories have also set up research parks. In 1998, Sandia National Laboratory turned to the National Academy of Sciences to help it plan a new research park. Jackie Kerby Moore, Executive Director of Sandia Science and Technology Park (SS&TP), explained that the original vision was to create "a place that would serve as a partnership tool for Sandia by providing direct access to industry science and technology to further the labs' mission."

Initially, Kerby Moore explained, SS&TP's purpose was to serve Sandia by bringing new ideas to the lab and marketing products developed by researchers at the lab, as well as providing individuals access to some otherwise inaccessible parts of the lab. It is now an internationally recognized, master-planned system, and while Sandia does not own any of the land on which the park is housed, it is in charge of the daily management, executive overview, and vision. The park has received many awards over the years, including the Outstanding Research Park of the Year from the Association of University Research Parks, the Outstanding State and Local Economic Development from the Federal Laboratory Consortium, the Technology-Led Economic Development Award from the U.S. Department of Commerce Economic Development Administration, and the Partnership Award from the International Economic Development Council.

Kerby Moore cited a couple of specific success stories that developed from SS&TP. EMCORE, a company that produces solar photovoltaic cells, moved to New Mexico from New Jersey after working with the park and licensing technologies from the labs. The CEO is a former Sandia employee with a background in photovoltaic cell research. The company recently opened a 17-acre solar farm in the park. TEAM Technologies, which was already based in the park, wanted to expand its operations. It licensed "Stingray," an improvised explosive device detection technology, from Sandia and has manufactured and shipped over 7,000 units to Afghanistan.

The park has also allowed Sandia to move some user facilities such as the Computer Science Research Institute, the Cyber Engineering Research Laboratory, and the Center for Integrated Nanotechnologies off campus, opening them up to even more users.

Kerby Moore explained that Sandia is very interested in creating an "incubator-like space" or a proof of concept program. Originally, this was not part of the design of the park because the need was not seen as pressing. The University of New Mexico (UNM) already had an incubator. But UNM had very little land, whereas SS&TP had plenty. The two institutions started to work collaboratively to foster new companies. Kerby Moore clarified that SS&TP is continuing to explore new ways to increase technology transfer income.

Sandia National Labs is not the only national laboratory that has set up a research park. Kerby Moore and Wessner named multiple facilities such as NASA's Research Park at NASA Ames, Oak Ridge Science & Technology Park at Oak Ridge National Laboratory, and the Livermore Valley Open Campus, which is associated with Lawrence Livermore National Laboratory and the Sandia National Laboratories California site.[6]

Perhaps the most unusual research park arrangement was discussed by Lewis Branscomb. The Joint Institute for Laboratory Astrophysics (JILA) in Colorado is actually only an agreement between the University of Colorado at Boulder and the National Institute of Standards and Technology (NIST) to share a common geographic location and set of expertise. JILA has no employees, but researchers from both the university and NIST work at the institute. The university owns the land and the facilities, but NIST rents half; NIST provides the instrumentation and funds research staff. Most of the research grants, however, come through the university researchers. The park is guided by a group of JILA fellows who strive to ensure that the collaboration is mutually beneficial. Branscomb stated that this was not a particularly difficult task because both partners are highly motivated to perform excellent research.

Eileen Walker provided examples of other successful research parks that had developed their own modes of operation. The Cummings Research Park in Huntsville, Alabama, has 285 companies with 25,000 employees on an 11 million square foot park. The focus is mainly on aeronautics, due to its association with NASA's Marshall space flight center and United States Army's Redstone Arsenal, but some biotechnology firms are also present. Clemson University's International Center for Automotive Research was started when BMW asked the university to develop a program and facilities for automotive research. More traditionally, both Purdue University and the University of Wisconsin, Madison, have research parks that were developed to capitalize on their traditional research strengths—engineering for Purdue and biotechnology for Wisconsin.

Wessner also provided some examples of research parks with which STEP had interacted. In particular, he described the Tech Valley Cluster in Albany, New York, a joint investment by the state of New York and IBM in the College of Nanoscale Sciences and Engineering of State University of New York, Albany. The intended goal is to develop a full workforce pathway in the nanoscale sciences and technologies. Wessner reminded the workshop attendees that, when thinking about parks from a university perspective, the investment is to benefit everyone; "It is important for academia to remember that it is not just investing in the university alone: you need to invest in the whole network. And to the extent that you can work through those shared facilities, and perhaps more importantly, common purpose, you can do better."

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[6] It should be stressed that many national labs have research parks; SS&TP and the collaboration at JILA are simply representative examples.

Many of the participants identified networking and cultural exchange as major benefits of research parks and described programs designed to facilitate mentoring, informal networking, and the movement of personnel.

Kerby Moore described SS&TP's Entrepreneurial Program, which gives leave to Sandia employees for up to two years to start or expand companies and guarantees their jobs upon return. Sandia is also starting a retiree mentoring program at the request of some former employees who wish to stay involved and provide guidance to new companies.

Such formal systems, however, are not always necessary. Paul Citron, a member of COSEPUP and former Vice President for Technology Policy and Academic Relations of Medtronic, Inc., and Lewis Branscomb mentioned high-innovation cities such as San Diego and San Francisco where a culture of communication and interaction took shape without institutional help. Branscomb pointed out that "the ability of a community to take risks is crucial to innovation." The success of the innovation system in San Diego illustrates that research parks are not essential to develop capacity, but it provides an example of the type of innovation environment that research parks can try to create. In general, the key to much of the success of the U.S. innovation system is the willingness to accept that some ideas will fail and to then learn from these failures, said Branscomb, and "this is not true in other parts of the world."

## INTERNATIONAL PARKS

The research park model has spread quickly in Asia and Europe, though the university role is smaller in those areas. Walker explained that in many regions, governments are funding research parks that are then "poaching" U.S. companies by offering cheap land and labor. Wessner mentioned some examples of research parks in China and Singapore that have benefited greatly from directed government investment and interest. In Europe, he described programs that span the entire European Union as well as those that are country specific, such as French incentives for collaborations.

The best known international system is probably the Fraunhofer Institutes in Germany. With funding from the federal government, state government, and industry, the institutes conduct application-oriented research of use to industry, the service sector, and public administration. They also operate a number of Fraunhofer Academies that provide sophisticated vocational training. This model is now migrating to the United States. Darmody discussed Fraunhofer USA programs in Maryland and Delaware that focus on software and bioengineering, respectively. But this system should be embraced cautiously, said Wessner. It has helped Germany sustain its manufacturing sector, but it has not produced game-changing start-ups or innovative new products.[7]

## THE IMPORTANCE OF LOCALIZATION AND SCALE

All the participants agreed that there is no single model for a research park. Each park must be designed to suit its particular region, available resources, and economic needs. Walker pointed out that parks require active interaction with a locus of research such as a university or national lab, a long-term perspective, a respectful leadership, and a willingness to adapt to evolving conditions. Wessner and Hardin specified that parks are also useful for forming clusters of capacity that are valuable for attracting businesses to a region. The symbiotic relationship between research parks and the surrounding region is crucial to the innovation ecosystem. Branscomb pointed out that not only is localization of a park going to happen, it is necessary for successful development.

Research parks generally focus on working with existing companies rather than nurturing start-ups. However, some parks have begun to add incubators that cater to the needs of entrepreneurs. This is consistent with the original impetus to create parks that fill in gaps that exist in the local economy and innovation ecosystem.

Hardin stressed that research parks must keep evolving and responding to competition, pointing out that even Research Triangle Park needs an upgrade. Walker noted that in identifying best practices that have emerged from years of research park experience one key element is that a park must have "a self-supporting business model in balance; even with all the other player[s], it needs to be able to take care of itself."

It was generally agreed that scale matters and that some research parks are simply not big enough to make a difference. However, research parks do not have to re-create every aspect of Silicon Valley to be successful. They can stimulate the economy by enhancing capacity enough to support higher-value activities and attract business investment. Research Triangle Park is a perfect example. As Branscomb said: "The goal should be consistent with what should get done."

[7] A notable exception not mentioned during the workshop is the MP3 technology, developed at the German company Fraunhofer-Gesellshaft.

# 6

# Public Policies to Support Innovation

The discussion of innovation at both workshops turned repeatedly to public policies that have hindered innovation in the past, are enhancing innovation currently, or could promote innovation in the future. The parts of the discussion related to these policies are gathered in this final chapter of the summary as a guide to possible future actions.

## HOW CAN THE BENEFITS OF INNOVATION BE RETAINED?

The United States does not have an innovation problem, said Borrus, given the "massive amounts" of innovation occurring at research universities. Rather, the United States has a problem benefitting from the innovations that occur in its universities. In a global economy, capital, technology, and increasingly people flow across national boundaries quickly.

Private capital markets in the United States also are reluctant to finance the scale-up of a first new facility in a fundamentally new area, Borrus said. As a result, innovators often have to go outside the United States to find the capital for such a facility. Otherwise, said Borrus, "you close the company, or you sell the intellectual property and whatever assets have been developed." The Department of Energy hoped to solve this problem in the energy area through a large loan guarantee program, but the program encountered strong political headwinds after the bankruptcy of the Solyndra solar cell company. And even before that, according to Borrus, the program was operated so conservatively that it did not do what it was intended to do. It would only fund proven technologies, much as a commercial bank would do.

In exploring ways to retain the benefits of innovation in the United States, Borrus emphasized the need to hear from young researchers, innovators, and entrepreneurs. People in their 20s and 30s have grown up in a world radically different than the world experienced by older people, he said. "People younger than 25 are thinking in a completely different way than we might think, and that set of perspectives would be very useful for COSEPUP."

## REGULATION

Overly cautious or burdensome regulations can be another reason why innovations originating in the United States are commercialized elsewhere. For example, it can be easier to do the clinical trials of a new cancer drug in China than in the United States because of access to a large population, lower costs, and a cooperative government, said Hennessy. Citron highlighted the fact that the regulation of medical devices also poses many barriers to their commercialization in the United States, which means that these devices often are developed elsewhere and subsequently imported into the United States, even if they are based on ideas that originated in U.S. universities.

The Food and Drug Administration (FDA) has a very difficult job, Hennessy acknowledged. The agency is charged with protecting the safety of the American public, and drug companies sometimes have broken the rules established to protect public safety. But the FDA has responded by setting up barriers that can make it very difficult for small companies to get products to the marketplace. Perhaps the FDA could establish separate categories for companies with stellar safety records and those with less than stellar records, Hennessy suggested. Another possibility would be to prioritize the review of important drugs with the potential to produce great benefits ahead of drugs intended to produce incremental improvements.

In the past, said Borrus, when many U.S. industries were globally dominant, the country could afford to pay the costs associated with stringent regulations in such areas as health, safety, and environmental regulation. "I'm not saying do away with regulation," he said, "but I do recommend taking a good hard look at all of the costs of doing business in a given area, where you are trying to commercialize a risky new set of technologies. . . . Things take too long, it's too risky, and there are disincentives that tend to keep capital abroad." By prudently lowering the costs of doing business, the United States could create an environment that is much more attractive to investors.

Edward Penhoet mentioned one particular approach to reducing the burden of regulations. As a member of the President's Council of Advisors on Science and Technology (PCAST), he has been involved in a review of the National Nanotechnology Initiative undertaken every two years in response to a request from Congress. The most recent nanotechnology report called on the nation to invest in regulatory science, which Penhoet defined as "the science that needs to be done to make an informed regulatory decision."[8] In nanoscience, for example, federal agencies fund studies of the effects of nanoparticles on cell cultures, but they do not support work, either individually or collaboratively, on the problem of how to move nanoparticles toward approval by the Environmental Protection Agency or the FDA.

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[8] President's Council of Advisors on Science and Technology. 2012. *Report to the President and Congress on the Third Assessment of the National Nanotechnology Initiative.* Washington, DC: Executive Office of the President.

PCAST also has been involved in an examination of the drug approval process at the FDA, Penhoet said.[9] Today, the FDA simply counts the number of drugs it has approved as a measure of its impact, but many of these drugs have only incremental effects on the lives of patients. A much better measure is the impact of the new products the FDA approves. In particular, PCAST recommended a more facile way of dealing with breakthrough drugs.

PCAST has also recommended reforms in the way clinical trials are done in the United States. For example, clinical trials are currently hampered by the need to gain approval from the institutional review boards at each institution participating in a trial. A more consolidated and streamlined review process could speed up drug development. Finally, Penhoet mentioned that the pharmaceutical industry could benefit by much more collaboration on precompetitive research that takes place before companies are in a position to compete in the marketplace. “There is an effort now to open up much more transparency in the drug development process,” he said. Citron added that the regulatory process governing medical devices is similarly in need of review and reform.

## SUPPORT FOR RESEARCH AND DEVELOPMENT

The government has many ways of spurring investments in innovation beyond direct support for research and development, noted several speakers, including modification in its tax, regulatory, and trade policies. For example, the capital gains tax could be restructured in a way that further incentivizes investors to focus on a company’s long-term vision of its future rather than on short-term fluctuations in the company’s value, which tends to be the case today. A more exotic possibility discussed briefly at the first workshop would be to allow copyrighting of basic research for a long period— say, 75 years— and allow the holder of the copyright to charge a very small royalty for use of the results. Such an action would pose many practical difficulties but also would funnel money back into research while simultaneously allowing the uses of research to be tracked.

Recognizing that the availability of venture capital for particular fields goes through cycles, workshop participants asked whether one role of government might be to invest against the cycles. Support for broad thematic areas that are currently out of favor could maintain activity and capacity until private sources of support recover.

Foundations can be more innovative and nimble than government and should not assume that their efforts will be dwarfed or mirrored by those of the federal agencies, several speakers observed. For example, the Gordon and Betty Moore Foundation has supported the Public Library of Science and the Marine

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[9] President’s Council of Advisors on Science and Technology. 2012. *Report to the President on Propelling Innovation in Drug Discovery, Development, and Evaluation.* Washington, DC: Executive Office of the President.

Microbiology Initiative. Similarly, the Howard Hughes Medical Institute, which supports investigators rather than projects, uses a funding model that is different from and complementary to those of federal agencies. Relatively few foundations currently fund science and technology— even among those established on the basis of technological advances. Yet foundations could have a disproportionate impact on science by funding relatively risky projects that federal agencies do not fund or by supporting especially promising researchers. The role of foundations in science and technology could be the subject of an interesting workshop by COSEPUP or another organization, some participants suggested.

Hennessy, who recently joined the board of the Moore Foundation, said that he is dismayed about the trajectory of funding for science and the growing risk aversion and unwillingness of government to play a role in precipitating the development of new areas. Government agencies used to be willing to support the initial development of entirely new areas of technology, as when the Defense Advanced Research Projects Agency catalyzed the very-large-scale integration revolution in semiconductors and the creation of the Internet. But agencies have become more risk averse over time. Foundations may be part of the solution to this problem, especially as more foundations are established that have a commitment to science. They could share best practices and form alliances to support faculty, especially young faculty, who are trying to take risks and are unable to get support. For example, the Alfred P. Sloan Foundation and the Moore Foundation are collaborating on a new program around the concept of big data, and others such as the Simons Foundation and the Kavli Foundation are supporting science. "Over time you might have a constellation of 10 foundations doing this. It could make a big difference in terms of funding early startup work."

With regard to a suggestion that endowment funding be used to smooth the ups and downs of federal research funding, Hennessy said that endowments would have to grow substantially to do so. He also said that to some extent the university has done that. Over the last 30 years at Stanford, the largest supporter of graduate students has shifted from the federal government to the university endowment, and the endowment has helped drop the average net cost of attendance at Stanford. Similarly, when he arrived at Stanford, the expectation was that all junior engineering faculty would pay their entire summer salaries and 25 percent of their academic salaries through government research, and that senior faculty would pay 50 percent of their academic salaries. Since then, the engineering school has raised the money to support 40 faculty chairs, and the academic year offset has fallen to 10 percent.

However, as federal funding drops, universities will not be able to fill the entire research funding gap with their own resources, said Hennessy. "There is no way the university is going to step up and plug the hole, particularly with all the acute pressure around tuition and how fast tuition can go up."

The loss of the charitable deduction in the tax code would hurt universities, especially with medium-sized and small donors, which provide a considerable portion of the annual giving, Hennessy said. Stanford, for example, supports about 1,200 undergraduate scholarships and about 200 graduate fellowships with annual gifts given to support those students. "For the vast majority of universities, big gifts are not where the action is. It's the smaller and medium-sized gifts."

## FEDERAL INPUT IN RESEARCH PARKS

In consultation with the Innovation Coalition, a collaborative group of national innovation- based associations, including some of the participants of the second workshop representing research parks, Brian Darmody of the University of Maryland prepared a list of federal actions designed specifically to make research parks more effective:

- Improve technology transfer by allowing federally supported researchers to devote five percent of grants to commercialization activities such as filing patents.
- Relax Internal Revenue Service rules on "private use" of research facilities built with tax-exempt bonds. Universities are wary of working too closely with industry because they fear they could lose their tax exempt status.
- Facilitate technology transfer from national labs by creating intermediary organizations to work with industry, and establish entrepreneur-in-residence programs at federal technology transfer offices.
- Expand the research and development tax credit to provide additional benefit to companies collaborating with universities.
- Reform export controls to focus on a smaller number of real dangers and to encourage university-industry collaboration.
- Embed entrepreneurship in STEM education.

## INTELLECTUAL PROPERTY PROTECTION

Intellectual property considerations vary widely across technological fields and even within fields. Some companies want patents to trade them or to cross-license with other companies. Other may seek to amass a large portfolio of patents in a field with very short product lifecycles in an effort to control the evolution of that field.

In some fields, such as pharmaceuticals, it takes a long time for innovations to reach the market, and patents are crucial to protect an idea until the innovator can profit from that idea. In other industries, patents are rare and are easy to work around when they do exist.

Sometimes the impact of patents within an industry can change over time. Before the establishment of Chiron, the diagnostics industry concentrated on building large instruments that could handle multiple tests, and the industry was focused on the efficiency of testing with little proprietary advantage, said Rutter. Several key patents granted to Chiron enabled the development of a vibrant diagnostics industry. Chiron's patents made it possible to invest in not only technology but discovery. The length of time that a patent can apply is a contentious public policy issue, Rutter acknowledged, "but some degree of protection in this area has been important for the development of the whole industry."

The stage of development of a technology also can be important. SPICE and RISC are both examples of technologies that developed from precompetitive research conducted before commercial products were imminent. Once the ideas had been developed, multiple people and companies could develop proprietary products based on those ideas. In addition, these companies could take advantage of the people who had helped develop those technologies in universities.

Because some technologies take longer to develop than others, Cui wondered whether more of the groundwork for developing a commercial technology could be done in universities before moving that technology into a commercial setting. Research costs are much less in a university than outside a university, where equipment, people, and space must be paid for. Within a university, innovators have excellent infrastructure, colleagues with whom to discuss problems, and excellent graduate students. The research done in universities needs to be open so that graduate students can publish their work and advance their careers. But research done in a university laboratory and in a commercial laboratory can be synergistic, with each supporting the other.

Hennessy agreed that such an approach is possible but raised several concerns. Graduate students may be a cheaper form of labor, but they are at the university for an education, and that education should not be sacrificed to develop a commercial product. The costs may be greater outside a university, but university research has costs as well. Conflict of interest issues can usually be resolved, said Hennessy, but they can become severe when research inside a university is tightly linked with commercial concerns or what an outside company is doing. Conflict of interest is less of a problem in the information technology sector, where the transfer of technology outside of the university is typically quick and sharp. But it can happen in the life sciences sector, and universities have had some "ugly incidents" involving conflicts.

## THE GLOBALIZATION OF INDUSTRY

Living in a global economy means that Americans should not be overly concerned about whether an American-owned company or a foreign-owned company commercializes a product in the United States, said Borrus. Foxconn, a Taiwanese company, is building a large plant in Texas to build products for Apple, with financial incentives from the state, just as many large foreign pharmaceutical and automobile companies have invested in U.S. production facilities. The United States benefits both from these investments and from the spillover effects of having production occur in this country. Also, in this light, trade wars are counterproductive, because part of a company may be in the country with whom a trade war is being fought. "It shouldn't matter to us who is doing the investing so long as the investment is happening here," said Borrus. The United States needs "to create an environment that encourages more of that investment, . . . because at the end of the day, that's where the economic benefits and long-term growth prospects for the U.S. economy lie."

This last point generated considerable discussion among the attendees and the COSEPUP members. Penhoet pointed out that economic gain is no longer synonymous with ownership. Others observed that companies are owned by whoever buys their stocks. The German company Siemens has more U.S. employees than German employees. Foreign companies may have their headquarters in the United States or elsewhere, but the distinction does not necessarily matter.

However, countries do have an interest in where companies decide to invest their profits. Thus, the United States has an interest in having companies in this country that are successful and profitable regardless of ownership.

Ruth David, a member of COSEPUP at the time of the workshops and President and Chief Executive Officer of ANSER (Analytic Services, Inc.), brought up the idea that some foreign-owned companies generate concern in the United States over corporate espionage (though some U.S. companies are viewed in much the same way in other countries). On the one hand, foreign companies in the United States are seen as interdependent economically. On the other hand, they are seen as a threat to national security. Policy makers need to be educated about how to reconcile these perspectives and grasp the interdependent complexity of the global economic system, so that when they move to change one part of the system they have a sense of how that change will affect other parts of the system.

Even startup companies now tend to be multinational, especially if they are involved in the manufacturing of hardware. Multiple participants noted that many U.S. startup companies also move quickly to establish foreign operations to improve access to markets, information, and talent. Entrepreneurs therefore need to know how to manage a global supply chain and be comfortable in an international setting.

Global investment decisions are changing because of the growing availability of fossil fuel energy in the United States, several speakers and COSEPUP members pointed out. The United States will gain a large competitive advantage over many other developed countries because of its abundant supplies of relatively inexpensive natural gas and other fossil fuels. Even basic manufacturing of products like cement or aluminum may shift back to the United States because of cheap energy. But this manufacturing will look much different than earlier generations of basic manufacturing. It will have a much greater component of information technology and robotics, requiring that the workers in these companies have higher and different skills than in the past.

## EDUCATION AND TRAINING

Finally, education and training were frequent topics of discussion at the workshop. Penhoet, for example, described a PCAST report entitled Engage to Excel: Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering, and Mathematics, which focused specifically on the first two years of college for students interested in STEM fields.[10] As that report pointed out, fewer than 40 percent of students who enter college intending to major in a STEM field complete a STEM degree, and the greatest loss of those students occurs during the first two years of college. Yet the United States has many jobs in technical fields for which U.S. workers do not have the needed skills. The report heavily engaged representatives of community colleges, which do much of the training for technical jobs in the United States and are extensively involved with the first two years of STEM education in college. It urged colleges and universities to think in a very different way about how they teach science courses to students so that students are more engaged in what they are learning and less likely to leave STEM fields for other majors. The report, as well as an earlier PCAST report on K-12 education, have received strong support from the Obama administration, which has adopted and promoted many of the recommendations from the report.

Given the difficulty of attracting sufficient U.S. students to STEM fields, the United States will depend on the inflow of foreign graduate students in these fields for the foreseeable future, said Hennessy. “We should try to figure out how to make it work.” He agrees with many others that students who earn a PhD in a STEM field from a U.S. university should automatically qualify for permanent resident status in the United States. People are mobile globally, and many scientists, engineers, and innovators still want to come to the United States or stay in the country once they earn degrees from U.S. colleges and universities. More rational immigration and naturalization policies would benefit the United States, Hennessy said, specifically of highly educated individuals, whether they have degrees from U.S. institutions or from universities in other countries.

[10] President’s Council of Advisors on Science and Technology. *Engage to Excel: Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering, and Mathematics*. 2010. Washington, DC: Executive Office of the President.

# Appendixes

# Appendix A
# Workshop Agendas

NATIONAL ACADEMY OF SCIENCES
1863–2013 • Celebrating 150 Years of Service to the Nation

WORKSHOP ON TRENDS IN THE INNOVATION ECOSYSTEM:
CAN PAST SUCCESSES HELP INFORM FUTURE STRATEGIES?

Xerox PARC
3333 Coyote Hill Road
Palo Alto, California 94304

**TUESDAY, 26 FEBRUARY 2013**

| | | |
|---|---|---|
| | **OPEN SESSION** | |
| 8:45 AM | **Introduction, Opening Remarks, and Meeting Objectives**<br>Each panel discussion will have a specific focus, but a few core questions will underlie all of the discussions.<br>▪ What were the key ingredients to earlier successes?<br>▪ Why did some ideas/projects fail?<br>▪ Would the same approaches succeed today?<br>▪ What is the most effective role for university researchers?<br>▪ What are the weak spots in the innovation process?<br>▪ How is innovation likely to change?<br>▪ How does public policy help or hinder innovation today? | **Richard Zare**, Chair<br>**Kevin Finneran**, Director |
| 9:00 AM | **What were the keys to early successes?** | **David Hodges,** Berkeley<br>**Eli Yablonovitch,** Berkeley<br>**Bill Rutter,** Chiron |

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|---|---|---|
| 10:15 AM | **How does innovation differ among sectors? How is it changing?** | **Yi Cui,** Stanford<br>**Steven Quake,** Stanford |
| 11:30 AM | **Lunch with Speaker** | **John Hennessy,** Stanford |
| 1:15 PM | **Creating an environment for innovation** | **Michael Borrus,** X/Seed<br>**David Mowery,** Berkeley Business School<br>**Ed Penhoet,** Chiron, PCAST |
| 3:00 PM | **Break** | |
| 3:15PM | **COSEPUP discussion** | **Richard Zare**, Chair<br>**Kevin Finneran**, Director |
| 5:15 PM | **Adjourn** | |

NATIONAL ACADEMY OF SCIENCES
1863–2013 • Celebrating 150 Years of Service to the Nation

WORKSHOP ON TRENDS IN THE INNOVATION ECOSYSTEM:
THE ROLE OF RESEARCH PARKS

The National Academies Keck Center
Room 204
500 Fifth Street NW, Washington, DC 20001

Teleconference Participants
Call-in Number: 1-(866) 715-2135; Passcode: 6685394

**MONDAY, 20 MAY 2013**

| **OPEN SESSION** | | |
|---|---|---|
| 8:00 AM | **Continental Breakfast** | |
| 8:30 AM | **Introduction and Opening Remarks** | **Richard Zare**, Chair<br>**Kevin Finneran**, Director |
| 8:35 AM | **Research Parks – Panel 1** | **Charles Wessner**, NAS<br>**John Hardin**, NC Dept. of Commerce<br>**Jackie Kerby Moore**, Sandia S&T Park |
| 10:00 AM | **Break** | |
| 10:30 AM | **Research Parks – Panel 2** | **Brian Darmody**, U. Maryland<br>**Lewis Branscomb**, JILA<br>**Eileen Walker**, AURP |
| 12:00 PM | **Lunch** | |

# Appendix B
# Speakers at the Workshops

*Palo Alto, California, February 26, 2013*

- Michael Borrus, Founding/Managing General Partner at X/Seed Capital Management
- Yi Cui, Associate Professor, Department of Materials Science and Engineering, Stanford University
- John Hennessy, President, Stanford University
- David Hodges, Daniel M. Tellep Distinguished Professor of Engineering Emeritus, University of California, Berkeley
- David Mowery, Milton W. Terrill Professor of Business, Walter A. Haas School of Business, University of California, Berkeley
- Ed Penhoet, Director, Alta Partners; Chairman and CEO Emeritus of Chiron Corporation
- Steven Quake, Professor of Bioengineering, Stanford University, and Investigator, Howard Hughes Medical Institute
- William Rutter, Chairman and CEO of Synergenics, LLC; Chairman Emeritus of Chiron Corporation
- Eli Yablonovitch, Director, NSF Center for Energy Efficient Electronics Science, University of California, Berkeley

*Washington, District of Columbia, May 20, 2013*

- Charles Wessner, Associate Director, Board on Science, Technology, and Economic Policy, National Academy of Sciences
- John Hardin, Executive Director, North Carolina Board of Science and Technology, Office of Science and Technology, North Carolina Department of Commerce
- Jackie Kerby Moore, Executive Director, Sandia Science and Technology Park
- Brian Darmody, Associate Vice President for Research and Economic Development, Director of Corporate Relations, University of Maryland; Special Assistant Vice Chancellor for Technology Development, University System of Maryland
- Lewis Branscomb, Co-founder of the Joint Institute for Laboratory Astrophysics (JILA) , University of Colorado University/National Institute of Standards and Technology; Adjunct Professor, School of International Relations & Pacific Studies, University of California, San Diego
- Eileen Walker, Chief Executive Officer, Association of University Research Parks

# Appendix C
# Speakers Biographies

**MICHAEL BORRUS** is the founding general partner of X/Seed Capital, a seed-focused early stage venture fund. Prior to X/Seed, he was Executive in Residence at Mohr Davidow Ventures (MDV). Previously, Borrus was Managing Director of The Petkevich Group (TPG), a start-up merchant bank providing financial advisory services and investment capital to growth companies in life sciences and technology. Before TPG, Michael was Adjunct Professor in University of California, Berkeley's College of Engineering, Co-founder and Co-Director of the Berkeley Roundtable on the International Economy (BRIE) at the University of California, Berkeley, and a partner in Industry and Trade Strategies, a business consultancy. He is the author of three books, has appeared in numerous media outlets from CNN and NPR to the New York Times, and serves on the Advisory Committee to the U.S. Government Advanced Technology Program (ATP). Borrus is an honors graduate of Harvard Law School, the University of California, Berkeley and Princeton University. He is a member of the California State Bar.

**LEWIS M. BRANSCOMB** was the Co-founder of the Joint Institute for Laboratory Astrophysics (JILA) at the University of Colorado. He holds appointments as a Research Associate at the Scripps Institution for Oceanography and the University of California, San Diego, the Aetna Professor of Public Policy and Corporate Management, emeritus, at Harvard University, director emeritus of Harvard's Science, Technology, and Public Policy Program in the Belfer Center for Science and International Affairs, and a member of the Center's Board of Directors. Branscomb pioneered the study of atomic and molecular negative ions and their role in the atmospheres of the earth. After serving as director of the U.S. National Bureau of Standards (now the Institute for Standards and Technology) from 1969–1972, he was named vice president and chief scientist of IBM Corporation and a member of the IBM Corporate Management Board. In 1980, President Jimmy Carter appointed him to the National Science Board and he was elected chairman, serving until May 1984. Branscomb was also appointed by President Lyndon Johnson to the President's Science Advisory Committee (1964–1968) and by President Ronald Reagan to the National Productivity Advisory Committee. He is a member of the National

Academy of Engineering (NAE), the National Academy of Sciences (NAS), the Institute of Medicine (IOM) and the National Academy of Public Administration. He served twice as a director of the American Association for the Advancement of Science (AAAS), member of the NAS Council and of the Governing Board of the National Research Council. He is a former president of the American Physical Society and a former president of Sigma Xi. He is a recipient of the Vannevar Bush Award of the National Science Board, the Arthur Bueche Award of the National Academy of Engineering, the Gold Medal of the U.S. Department of Commerce, and the Okawa Prize in Communications and Informatics. He received the Centennial Medal of the Harvard University Faculty of Arts and Sciences in 2002. He holds honorary doctoral degrees from sixteen universities and is an honorary associate of the Engineering Academy of Japan and an Associate member of the Russian Academy of Sciences. Branscomb received his B.A. in physics, summa cum laude, from Duke University in 1945 and Ph.D. in physics from Harvard in 1949, when he was appointed Junior Fellow in the Harvard Society of Fellows.

**YI CUI** is an Associate Professor in Department of Materials Science and Engineering at Stanford University. His current research is focused on nanomaterials for energy storage, photovoltaics, topological insulators, biology and environment. He is the Co-Founder and Director of Amprius, Inc, a start-up that focuses on battery technology developed from his research at Stanford. He has received the Sloan Research Fellowship (2010), the Global Climate and Energy Project Distinguished Lecturer (2009), King Abdullah University of Science and Technology (KAUST) Investigator Award (2008), Office of Naval Research (ONR) Young Investigator Award (2008), MDV Innovators Award (2007), Terman Fellowship (2005), the Technology Review World Top Young Innovator Award (2004), Miller Research Fellowship (2003), Distinguished Graduate Student Award in Nanotechnology (Foresight Institute, 2002), Gold Medal of Graduate Student Award (Material Research Society, 2001). Cui received a Bachelor's degree in Chemistry from the University of Science and Technology of China and his Ph.D. from Harvard University, in semiconductor nanowires.

**BRIAN DARMODY** is Associate Vice President for Research and Economic Development, Director of Corporate Relations, and Special Assistant Vice Chancellor for Technology Development, University System of Maryland. He is responsible for developing linkages with private and government sectors, and developing projects funding opportunities and policies to support these initiatives. In his role with the University System of Maryland, he focuses on improving technology commercialization across the University System of Maryland and issues supporting university-federal lab partnerships. He serves on state and national boards, including Fraunhofer USA, Alliance for Science and

Technology Research America (ASTRA), National Association of Seed and Venture Funds (NASVF), the Maryland Venture Authority. Projects led by Darmody include organizing the University's first technology transfer office, authoring reforms to the State's ethics legislation for entrepreneurial start-ups, developing legislation creating the Maryland Technology Development Corporation (TEDCO), and serving as Director of the University of Maryland Center for Applied Policy Studies (UMCAPS). He holds a Juris Doctor from the University of Baltimore and an undergraduate degree. from the University of Maryland, College Park.

**JOHN HARDIN** is the Executive Director for the North Carolina Board of Science & Technology, which is staffed by Office of Science & Technology in the North Carolina Department of Commerce. He was appointed Acting Director in spring 2008 and Executive Director in fall 2009. Previously, he served as the Board's Deputy Director and Chief Policy Analyst. The Board advises and makes recommendations to the North Carolina Governor, General Assembly, Secretary of Commerce, and Economic Development Board on the role of science and technology in the economic growth and development of the state. Hardin's duties include developing and justifying legislation related to defining statewide research capacity and structure; implementing science and technology-related economic development policy and resource allocations; research, analysis, and review of substantive policy issues and proposals; preparing public policy and budget analyses; preparing and presenting high-level state policy briefings, assessments, and reports to policy makers and external constituencies; conducting strategic planning and making recommendations for technology-based economic development; directing and overseeing strategic initiatives with impact at the state level; and overseeing the administration of grant programs to support technology commercialization by North Carolina small businesses. Before serving on the board, he was the Assistant Vice President for Research and Sponsored Programs in the University of North Carolina (UNC) General Administration. He currently holds an Adjunct Assistant Professor position in the Department of Public Policy at UNC-Chapel Hill, where he teaches courses on American politics, public policy, and policy analysis. A native of Tulsa, Okla., he holds M.A. and Ph.D. degrees in political science from UNC-Chapel Hill, and a B.A. in economics from Baylor University.

**JOHN L. HENNESSY** joined Stanford's faculty as an assistant professor of electrical engineering. He rose through the academic ranks to full professorship and was the inaugural Willard R. and Inez Kerr Bell Professor of Electrical Engineering and Computer Science from 1987 to 2004. Hennessy was director of the Computer Systems Laboratory, a research and teaching center operated by the Departments of Electrical Engineering and Computer Science that fosters research in computer systems design. He served as chair of computer science and dean of the School of Engineering, before he was named provost, where continued his efforts to foster interdisciplinary activities in the biosciences and bioengineering, and oversaw improvements in faculty and staff compensation. In October 2000, he was inaugurated as Stanford University's 10th president. In 2005, he became the inaugural holder of the Bing Presidential Professorship. Dr. Hennessy is a recipient of the 2000 Institute of Electrical and Electronics Engineers (IEEE) John von Neumann Medal, the 2000 American Society for Engineering Education (ASEE) Benjamin Garver Lamme Award, the 2001 Association for Computing Machinery (ACM0 Eckert-Mauchly Award, the 2001 Seymour Cray Computer Engineering Award, a 2004 NEC C&C Prize for lifetime achievement in computer science and engineering, a 2005 Founders Award from the American Academy of Arts and Sciences and the 2012 IEEE Medal of Honor, IEEE's highest award. He is a member of the National Academy of Engineering and the National Academy of Sciences, and he is a fellow of the American Academy of Arts and Sciences, the Association for Computing Machinery, and the Institute of Electrical and Electronics Engineers. He has lectured and published widely and is the co-author of two internationally used undergraduate and graduate textbooks on computer architecture design. Dr. Hennessy earned his bachelor's degree in electrical engineering from Villanova University and his master's and doctoral degrees in computer science from the State University of New York at Stony Brook.

**DAVID A. HODGES** is the Daniel M. Tellep Distinguished Professor of Engineering Emeritus at the University of California at Berkeley. He worked at Bell Telephone Laboratories in Murray Hill and Holmdel, NJ, before joining the faculty in Electrical Engineering and Computer Sciences (EECS) at UC Berkeley. Following a year as Chair of the EECS Department, he served as Dean of the College of Engineering. His teaching and research has centered on microelectronics technology and design, and semiconductor manufacturing systems. With Professor Robert C. Leachman, he founded Berkeley's Competitive Semiconductor Manufacturing Program. Hodges was the winner of the 1997 Institute of Electrical and Electronics Engineers (IEEE) Education Medal and the 1999 American Society for Engineering Education (ASEE) Benjamin Garver Lamme Award. He was the founding Editor of the IEEE Transactions on Semiconductor Manufacturing, a past Editor of the IEEE Journal of Solid-State Circuits, and a past Chairman of the International Solid-State Circuits Conference. With R. W. Brodersen and P. R. Gray, he received the 1983 IEEE Morris N. Liebmann Award for pioneering work on switched-capacitor circuits. He is a Fellow of the IEEE and a Member of the National Academy of Engineering. He is a former Director of Silicon Image, Inc. and of Mentor Graphics. He earned the B.E.E. degree at Cornell University and the M.S. and Ph.D. degrees at Berkeley.

**JACKIE KERBY MOORE** is the executive director of the Sandia Science & Technology Park and has been since its inception in 1998. In her role as executive director, Kerby Moore oversees all aspects of the Park – including the management, marketing, recruiting of tenant companies, and securing of funding for infrastructure improvements. In related activities, she is past president of the Board of Directors for the Association of University Research Parks. During her years leading the Association, she chaired the first-ever Washington, D.C. Summit on Research Parks. She serves on the Advisory Board for Arrowhead Research Park, the Business and Industry Advisory Cabinet for the Vice President of Research and Economic Development at the University of New Mexico, and she is a member of Albuquerque Economic Development, Albuquerque Hispano Chamber of Commerce, Association of Commerce & Industry, Greater Albuquerque Chamber of Commerce, New Mexico Economic Forum, and the International Economic Development Council. Kerby Moore has a Bachelors of Business Administration Degree and a Masters of Business Administration Degree from New Mexico Universities.

**DAVID MOWERY** is the William A. and Betty H. Hasler Professor of New Enterprise Development at the Walter A. Haas School of Business at the University of California, Berkeley and a Research Associate of the National Bureau of Economic Research. Mowery taught at Carnegie-Mellon University, served as the Study Director for the Panel on Technology and Employment of the National Academy of Sciences, and served in the Office of the United States Trade Representative as a Council on Foreign Relations International Affairs Fellow. He has been a member of a number of National Research Council panels, including those on the Competitive Status of the U.S. Civil Aviation Industry, on the Causes and Consequences of the Internationalization of U.S. Manufacturing, on the Federal Role in Civilian Technology Development, on U.S. Strategies for the Children's Vaccine Initiative, and on Applications of Biotechnology to Contraceptive Research and Development. During 2003-2004, he was the Marvin Bower Research Fellow at the Harvard Business School. His research deals with the economics of technological innovation and with the effects of public policies on innovation; he has testified before Congressional committees and served as an adviser for the Organization for Economic Cooperation and Development, various federal agencies and industrial firms. He received his undergraduate and Ph.D. degrees in economics from Stanford University and was a postdoctoral fellow at the Harvard Business School.

**ED PENHOET** is a Director of Alta Partners. He serves on the boards of directors of ChemoCentryx, Immune Design, Metabolex, Scynexis, and

ZymoGenetics. A co-founder of Chiron, Penhoet served as the Company's President and Chief Executive Officer from its formation in 1981 until April 1998. He is a member of the Independent Citizens Oversight Committee for the California Institute of Regenerative Medicine (CIRM), and recently served as the as President of the Gordon and Betty Moore Foundation. For 10 years prior to founding Chiron, Penhoet was a faculty member of the Biochemistry Department of the University of California, Berkeley. Penhoet is the immediate past Dean of the School of Public Health at the University of California, Berkeley. He is a member of the U.S. Institute of Medicine and the American Academy of Arts and Sciences.

**STEPHEN QUAKE** is a Professor of Bioengineering and of Applied Physics at Stanford University. After his postdoctoral work at Stanford, he joined the department of Applied Physics and Physics at the California Institute of Technology at the age of 26. In 2004, he moved back to join the newly formed Department of Bioengineering at Stanford. He has been an investigator with the Howard Hughes Medical Institute (HHMI) since 2006. His initial work focused on understanding the biophysics of DNA by building various tools and devices. Hearing about George M. Whitesides's work using polymeric microfluidics, he teamed up with Axel Scherer to develop inexpensive fabrication methods for microfluidic chips for Lab-on-a-chip applications. These new fabrication methods allow for the design of more complicated geometries allow for microfluidic large scale integration. Using these chips, the Quake group has been able to use the chips to create crystals for x-ray crystallography and single-molecule DNA sequencing. In addition to his work at Stanford, he is a cofounder of both Helicos Biosciences and Fluidigm Corporation. In 2002, he was named as one of the Technology Review's TR35. In 2004, he was the recipient of the National Institutes of Health (NIH) Director's Pioneer Award. He is the 2012 winner of the Lemelson–MIT Prize. He earned his B.S. in Physics and M.S. in Mathematics from Stanford and his D.Phil. in Physics from Oxford University in 1994 as a Marshall Scholar.

**BILL RUTTER** is Chairman and CEO of Synergenics, LLC, Chairman Emeritus of Chiron Corporation and Herzstein Professor of Biochemistry Emeritus at the University of California, San Francisco (UCSF) where he played a key role in developing UCSF in a major scientific contributor. Rutter previously served as a founder and Chairman of Chiron Corporation and member of the Board of Director of Ciba-Greigy/Novartis. He was instrumental in building Chiron into a global biotech power house. In 1999, Dr. Rutter founded Synergenics, LLC, which operates a consortium of commonly-owned but independent biotech companies offering an innovative and cost-effective approach to start-ups in the life sciences industry. In his academic career, Rutter was chairman of the Department of Biochemistry and Biophysics at the UCSF.

The department played a key role in developing recombinant DNA technology, genetic engineering and information of biotech companies to develop and exploit technology. During the early days in Chiron, he was concurrently the Director of the Hormone Research Institute at UCSF. Rutter and colleagues have published more than 380 scientific articles and hold more than 25 patents. His lab made several early contributions in biotechnology, including the first cloning of the insulin gene; the development of a process for making a vaccine against hepatitis B virus, the first vaccine based on recombinant DNA methodology. Rutter was elected to the National Academic of Sciences and American Academy of Arts and Sciences more than two decades ago.

**EILEEN WALKER** leads the Association of University Research Parks (AURP), which fosters innovation, commercialization and economic growth in a global economy through university, industry and government partnerships. The organization is comprised of university research, science and tech parks from all around the world. Walker regularly consults with universities and their research parks regarding best practices. In 2011, Walker was tapped by the State Department's Fulbright Foreign Scholarship Board to become a Fulbright Specialist, and serve as an advisor to foreign universities with their university research park initiatives. Her initial assignment was the Universidad de Antonio Nariño in Bogota, on planning for a new research park near Usme, Colombia. Prior to her current role with AURP, Walker directed the Arizona State University Research Park in Tempe, Arizona, for many years. She has served as a member of the Board of Directors of AURP; as an executive officer of the Arizona Bioindustry Association; and on the Board of Directors of Habitat for Humanity Tucson. She is a graduate of the University of Colorado at Boulder, and holds a Master of Business Administration in International Management from the American Graduate School of International Management.

**CHARLES WESSNER** is a National Academy Scholar and Director of the Program on Technology, Innovation, and Entrepreneurship. 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 studies centered on government measures to encourage entrepreneurship and support the development of new technologies and the cooperation between industry, universities, laboratories, and government to capitalize on a nation's investment in research. Foremost among these is a congressionally mandated study of the Small Business Innovation Research (SBIR) Program, reviewing the operation and achievements of this $2.3 billion award program for small companies and start-ups. He is also directing a major study on best practice in global innovation programs, and is involved in a complementary analysis best practice in state & regional innovation initiatives. The overarching goal of his 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.

**ELI YABLONOVITCH** is the Director of the NSF Center for Energy Efficient Electronics Science (E3S), a multi-University Center based at Berkeley. He is also the James & Katherine Lau Chair in Engineering and a Professor of Electrical Engineering and Computer Sciences at University of California, Berkeley. Previously, he worked for two years at Bell Telephone Laboratories, before becoming a professor of Applied Physics at Harvard. He then researched photovoltaic solar energy at Exxon, followed by some time at Bell Communications Research, where he was a Distinguished Member of Staff, and also Director of Solid-State Physics Research. In 1992 he joined the University of California, Los Angeles, where he was the Northrop-Grumman Chair Professor of Electrical Engineering. Yablonovitch is a Fellow of the Institute of Electrical and Electronics Engineers (IEEE), the Optical Society of America and the American Physical Society. He is a Life Member of Eta Kappa Nu, and is elected as a Member of the National Academy of Engineering, the National Academy of Sciences, and the American Academy of Arts & Sciences. He has been awarded the Harvey Prize (Israel), the IEEE Photonics Award, The Institution of Engineering and Technology (IET) Mountbatten Medal (UK), the Julius Springer Prize, the R.W. Wood Prize, the W. Streifer Scientific Achievement Award, and the Adolf Lomb Medal. He received his Ph.D. degree in Applied Physics from Harvard University in 1972. He also has an honorary Ph.D. from the Royal Institute of Technology, Stockholm, and from the Hong Kong Univ. of Science & Technology.