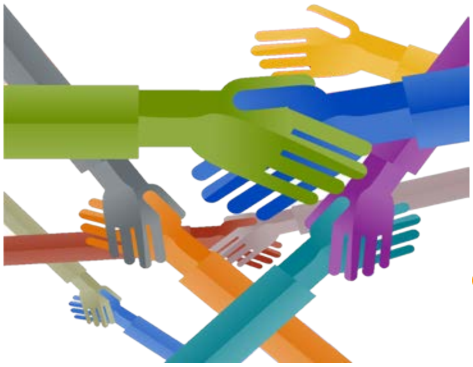
THE NATIONAL ACADEMIES

MEETING SUMMARY



CONVERGENCE

OPTIMIZING CROSS-SECTOR AND INTERDISCIPLINARY PARTNERSHIPS

Government-University-Industry Research Roundtable

June 2-3, 2014

Although traditional research methods have resulted in innumerable scientific discoveries, many of today's research questions are not effectively addressed within the context of a single scientific discipline. Convergence—the merging of previously distinct disciplines to create new disciplines—is emerging as a new model for scientific research and innovation. The Government-University-Industry Research Roundtable held a meeting to explore how convergence is created, what it has delivered to date, the advantages of convergence-driven research, the challenges to it, and the domains to which it can be applied in the near-term.

Dennis Ausiello, Director of the Center for Assessment Technology and Continuous Health (CATCH), Physician-in-Chief Emeritus at Massachusetts General Hospital, and Jackson Distinguished Professor of Medicine at Harvard Medical School, gave the keynote address on June 2.

Dr. Ausiello discussed the successes and the limitations of the genetic revolution. Perhaps the best articulation of the power of genetics has come out of personalized or precision medicine, particularly in the area of oncology. Ninety-five percent of cancers present with a somatic mutation that can be articulated as a drug target and could potentially lead to a treatment, if not a cure. Researchers have developed new skills and new toolkits to better stratify patients. For example, there are now 55 lymphomas instead of the three that were recognized when Ausiello was a resident.

This stratification is important, because it allows doctors to do what they most want to do, to use therapeutic and diagnostic input to provide patients with a real chance of success, rather than diagnostics that can be a shot in the dark. However, the ability to generalize this precision medicine paradigm to chronic diseases remains limited.

Right now, there is a convergence of three revolutions: genetic, digital, and integrative science. Going forward, all three of these will play a major role in understanding the human condition, explained Ausiello. The problem is that medicine has used the same measurements, such as heart rate, blood pressure, and hemoglobin A1C, for decades. We cannot begin to annotate the complexity of the human condition with an episodic, symptomatic approach.

With that in mind, Ausiello and his colleagues began a program between Massachusetts General Hospital and Massachusetts Institute of Technology (MIT) called CATCH—the Center for Assessment Technology and Continuous Health. CATCH is changing the landscape of how information is gathered. It aspires to measure the human phenotype with the same precision that we expect out of our genetic information, in real time, in order to provide a perpetual readout in the context of the multiple perturbations that occur in real life—sleeping, eating, exercising, and taking medication. Ultimately, CATCH aims to create new knowledge for health care performance that is lacking today.

Some of the work ahead will involve using data to better stratify patients, Ausiello explained. "For example, we do not know how to stratify the 33 to 34 million patients in the United States with type 2 diabetes and the multiple millions worldwide, and that needs to change," said Ausiello. In the next 10 years, he posited, diabetes will be 10 diseases instead of one. We spend a lot of time in medicine trying to homogenize patients (What do these patients have in common?) and we lose the opportunity to look at how they are different. Currently, there are 10 different drugs to treat multiple sclerosis, and doctors and patients need to use trial and error to find a drug to which each patient responds. By the time they find the right drug, the patient might have lost six to 10 years in the progression of the disease, which is not acceptable going forward. By interrogating real-time data on the quantity and duration of peoples' flares, researchers can begin to see subsets of patients that are significantly different both genetically and responsively.

One of the things we need to do better is to stratify our patients, said Ausiello. CATCH is emphasizing the novel phenotypes that need to be analyzed in the context of perturbations. For example, to learn more about how the immune system varies day to day and week to week, CATCH is developing technologies such as a patch that patients can wear that has 100 nanotubes that sample 10,000 macrophages a day. This technology would allow the researchers to begin to get a handle on flares and quiescence of diseases.

CATCH is working toward developing phenotypes at population scale, and the initiative is moving from research populations to real-world individuals. CATCH is embedded in a primary care practice. "If we can embed that in the clinical care, then we'll have an ecosystem that will really make a difference for all of us in all our professions," concluded Ausiello.

The first presentation on June 3, "Convergence: Examples from NSF of an Emerging Research Paradigm," was given by **Pramod Khargonekar,** the Assistant Director for Engineering at the National Science Foundation (NSF). Khargonekar explained how NSF is thinking about convergence by using examples, the first of which was tissue engineering and 3-D printing. In the 1970s and 1980s, NSF made early investments in these separate areas. Now, these two areas are converging. There is a tremendous explosion in trying to use approaches from 3-D printing to do tissue engineering—a development that shows the unpredictable nature of how things come together. NSF is building on that past; the agency had a workshop this summer on advanced biomanufacturing, which is the convergence of biology, materials science, process control, and engineering. "Is convergence a new paradigm?" asked Khargonekar, noting that Thomas Kuhn's *Structure of Scientific Revolutions* defines paradigm as a "universally recognized scientific achievement that, for a time, provides model problems and solutions for a community of practitioners." Khargonekar went on to say that decoding the genome would be an example of a new paradigm. We are in the early stages of figuring out whether convergence also fits the Kuhn model.

CHALLENGES OF CONVERGENCE DRIVEN RESEARCH

For Funding Agencies (like NSF): How do we identify new areas of convergence? How do we assess convergence-oriented proposals using the standard merit review process?

For Academic Institutions: How do we create flexible organizational structures to enable a convergence research paradigm change? How do we modify tenure and promotion processes so that faculty will be rewarded for taking risks in this new style of research?

For Industry: How does industry bring its tremendous know-how, which is not contained in research papers or textbooks, to this new way of doing research?

-Pramod Khargonekar, National Science Foundation

Another example of NSF's work around convergence was its funding of an Engineering Research Center (ERC) on synthetic biology seven or eight years ago at the University of California, Berkeley, with collaboration from Stanford; University of California, San Francisco; Harvard; and MIT. Synthetic biology demonstrates the convergence of engineering and biology. It envisions the engineering of interchangeable biological tools that repurpose nature to benefit mankind. So far, the ERC has built parts, devices, and circuits inspired by electrical engineering. Beyond its scientific achievements, the ERC explores questions of ethics and policy surrounding synthetic biology. In addition, the center has created a robust curriculum to teach the next generation of scientists and engineers. Since part of the ERC's mission is to transfer technologies to industry, five companies have spun off from its research.

Another area where NSF is supporting convergent research is its Cyber-Physical Systems (CPS) program, which has its roots in cybernetics, the idea of understanding and controlling communications in machines and animals. NSF's latest experiment in convergence is a program premised on a new way of thinking about infrastructure—one focused less on the physical objects and more on the services they provide.

In closing, Khargonekar noted the challenges and opportunities around convergence. For funding agencies like NSF: How do we maximize synergies within core programs and emerging areas of convergence? How do we identify new areas of convergence? How do we structure the merit review process to assess convergence-oriented proposals? For academic institutions: How do we create flexible organizational structures to enable a convergence research paradigm change? How do we educate students? How do we modify tenure and promotion processes so that faculty will be rewarded for taking risks in this new style of research? Scientific professional societies need to consider how they will adapt to convergence, because they are organized along disciplinary lines. Finally, how does industry bring its tremendous know-how—which is not contained in research papers or textbooks—to this new way of doing research? Khargonekar concluded by positing that success in this new world of research depends on inspiring new generations of researchers.

WHAT HAS CONVERGENCE DELIVERED TO DATE?

"Analytics show that when investigators move into one of NCRC's programs and leave their home departments behind, their productivity increases dramatically as evaluated by publications, grants, and internal review board applications."

-**Colin Duckett**, University of Michigan's North Campus Research Complex

The group next heard from a panel moderated by **Amanda Arnold** of Texas A&M University. **Colin Duckett,** Director of Program Development at the University of Michigan's North Campus Research Complex (NCRC), began by discussing "Fostering Convergent Scientific Research and Industry Engagement in a University Setting—Challenges and Strategies."

In 2007, Pfizer announced that it was closing down its Ann Arbor campus, and the University of Michigan purchased the entire campus, including its 28 buildings, for $108 million. The campus was so big that no single university unit could occupy the entire space. So, to use the campus effectively, the university has been obligated to foster convergent science, said Duckett. The North Campus Research Complex now has 2,500 employees, and somewhere between 800 and 1,000 new members will join it over the next year.

NCRC has had successes, as well as some initiatives that have fallen by the wayside, Duckett explained. Faculty members can join a NCRC program whether they come from pharmacy, dentistry, public health, engineering, or the medical school. Analytics show that when investigators move into one of NCRC's programs and leave their home departments behind, their productivity increases by roughly 30 percent in terms of publications, grants, and internal review board applications.

Dr. Duckett offered examples of a couple of programs that are doing well that constitute convergence. Biointerfaces is a collaborative program largely driven by biomedical engineering and by the engineering college, and involves the medical school, dentistry, and pharmacy. Currently, it has 21 labs that focus on a number of areas, such as biomaterials/drug delivery and nanotechnology. In the year-and-a-half the program has existed, its work has led to the formation of 11 start-up companies and the filing of 70 patents.

Biointerfaces also has a Grand Challenges program to spur collaborations. On certain Saturday mornings, any faculty member at the university can show up to chat with other faculty members about a given general topic and then break out into groups—it's a kind of speed-dating for the sciences, said Duckett. At the end of the day, faculty members write a grant application. Each application is required to involve people from multiple departments. The next day, the grants are awarded—usually $100,000 or $200,000 per application—and the researchers have a year to do something very different. This program has been very successful at driving collaborations, said Duckett.

Another program, which is university-wide and not limited to NCRC, is a program called MCubed. Each faculty member in the university is given a chip worth $20,000 but cannot cash in the chip unless he or she finds two additional faculty members from other departments or schools with whom to collaborate on a project. When the faculty members put their chips together, they have a $60,000 award for a research idea that does not need to undergo review. The University of Michigan is playing with these kinds of approaches to see if they can help faculty overcome the social and psychological barriers to collaboration, clarified Duckett, noting that NCRC is a great incubator to try innovations.

Melvin Greer, Senior Fellow and Chief Strategist at Lockheed Martin Information Systems and Global Solutions, followed with a presentation entitled "Workforce 2030: Impact of Convergence on Innovation." Greer noted that his boss considers convergence the most important technical development impacting the company. According to Greer, convergence is disrupting everything about Lockheed Martin's business, and it is reflective of the diversification of the business. Lockheed is not just a defense contractor and aerospace company but also a global energy company and a global health company as well. Greer discussed how convergence is not an education problem for Lockheed Martin; instead, it is a competitive advantage. The ability to compete and to offer complex solutions to their customers depends upon finding people who can be convergent in their thinking.

Lockheed hires about 20 percent of all of the engineers who graduate from U.S. engineering graduate schools, and they do not come with convergent research skills. They think that convergence is the same thing as collaboration or working in a team. However, convergence is not just about working with other people. "It is about harnessing the strengths from multiple science and research disciplines, processes, and solutions to accelerate innovation." So, Lockheed Martin is transforming engineering, the way they fund their research, the partners they look for, and the way they deliver results–all of these are changing based on a convergent mindset, Greer elaborated.

Mr. Greer discussed how innovation in convergence requires a focus on adaptive science, and Lockheed Martin is applying the concept of complex adaptive systems in robomorphics, biomimicry, synthetic biology, and nano sensors and fabrics. "This is not just a 2030 workforce issue," said Greer. "This is a 'today' workforce issue." Lockheed Martin has identified 20 of the top jobs that will soon exist that don't exist today, and the company is working with university partners to help them understand the curriculum that will be needed to produce people who can meet future workforce needs.

Lockheed's STEM and STEAM (**S**cience, **T**echnology, **E**ducation, **A**rts, and **M**athematics) efforts start far earlier than the university level–around fifth grade, when people begin to self-identify as interested in science. They aggregate partnerships to focus on development on STEM and STEAM programs that create this convergent style of engineering and this set of skills–the ability to collaborate, to have learning agility, to have cultural acumen, and to be digitally proficient.

Linda Nebeling, Chief of the Health Behavior Research Branch at the National Institutes of Health (NIH), spoke about "Transdisciplinary Research in Energetics and Cancer: Lessons Learned from a NCI Programs Perspective." For the past 10 years, she has directed a transdisciplinary initiative for the National Cancer Institute (NCI). At the time the initiative was starting around 2004, the relationship between obesity and cancer risk was becoming stronger in the evidence-based literature, and questions grew about the mechanisms underlying that relationship. Nebeling discussed how, in studying obesity and cancer, they wanted to use a transdisciplinary approach–one that brings together diverse disciplines of scientists to work jointly on a conceptual framework that synthesizes and extends discipline-specific theories, concepts, and methods to create new approaches to address a common problem.

Those familiar with the NIH funding structure, she posited, are used to working in multidisciplinary groups, where each discipline stays in its own little bubble or "piece of fruit within a fruit salad" while working together on a common problem. "When we're challenging you to work in transdisciplinary science, we're building a smoothie (see Figure 1). We're really shaking it up," Nebeling said. "We really want you to take what you know and blend it into a new scientific dynamic." So, NCI tried to adapt its funding structures to enable more fluidity.

The TREC initiative–**T**ransdisciplinary **R**esearch on **E**nergetics and **C**ancer–was funded starting in 2005. There were three to five primary transdisciplinary projects, with multiple projects looking at diet, obesity, and physical activity. Imagine having a conference with environmental scientists, transportation specialists, world-renowned cell and molecular biologists, oncologists, and behavioral scientists and trying to get them all to talk in the right tone and language.

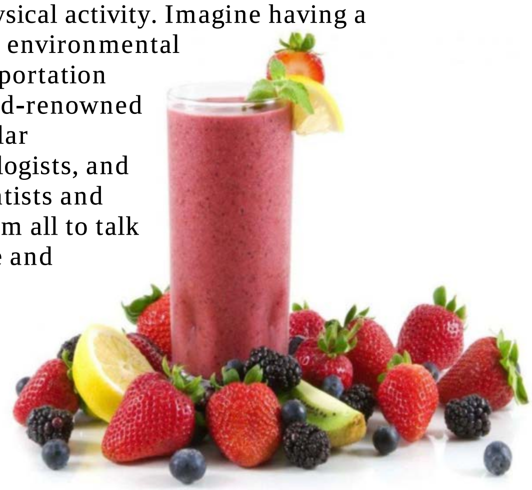


Figure 1. Convergence–Building a Smoothie
SOURCE: Presentation by Linda Nebeling, NIH, June 3, 2014

Creating the necessary common ground took about a year. Nebeling explained that the endeavor worked, thanks to multiple meetings, developmental pilot projects, cross-center working groups, and multiple training opportunities that allowed individuals to work cross-center.

In addition, Nebeling said that they were tracking and evaluating TREC from day one and observing how researchers built their networks and found ways to bridge into their transdisciplinary collaborations. Much of what was learned is now on NCI's Team Science Toolkit webpage, and it continues to be used by others.

Next, **Sonny Ramaswamy** from the USDA's National Institute of Food and Agriculture (NIFA) discussed "Crowdsourcing to Address Wicked Problems." Societal challenges are the drivers of NIFA's work, and Ramaswamy explained that he thinks of societal problems as wicked problems. The term "wicked problems" was invented by Horst Rittle in the early 1970s—the idea being that one can have the best knowledge and technology in the world and yet not be able to deploy it, because humans cannot agree on how to deploy the technology. So the problem becomes wicked. Therefore, the human dimension is a critical piece of everything NIFA does; it is important for stakeholders to be involved in the decision making process with regard to the discovery and deployment of new knowledge and new technologies.

The role of NIFA is to support user-inspired transdisciplinary work, he continued. NIFA provides funding in many different disciplines and identifies opportunities for convergence. NIFA deploys its competitive grants both in disciplinary research and in challenge areas, which are the wicked problems. A company called Chalklabs in Bloomington, Indiana, has been helping NIFA mine data on the science it is supporting. They are looking at the connections among biology, engineering, and the social sciences in order to identify networks that have formed because of the funding provided. Through data mining, Chalklabs is helping NIFA identify areas of convergence and project areas where it should be partnering.

Dr. Ramaswamy offered examples of the type of science NIFA is supporting. One project brings together biologists, engineers, and social scientists to study a plant pathogen that harms corn. Another project that brings together a huge suite of capabilities is called Conservation Effect Assessment Project (CEAP), which looks at how to manage water at the watershed level. NIFA also supports research in animal health that uses nano approaches to develop biosensors that can detect avian influenza virus. Other research projects focus on food safety, farmer safety, and the ecology and evolution of infectious disease.

In closing, Ramaswamy said that he disagrees with *Science* executive publisher Alan Leshner's assessment that convergence marks the end of disciplinary science. "You've gotta have deep disciplinary knowledge first, before you can make a smoothie," he said, expanding on Nebeling's analogy. Ramaswamy explained the need to figure out how to educate young people so they acquire deep disciplinary knowledge while also developing transdisciplinary skills.

Near-Term Applicable Domains for Convergence

"One current project brings together biologists, engineers, and social scientists to study a plant pathogen that harms corn. Another effort, called the Conservation Effect Assessment Project, looks at how to manage water at the watershed level. NIFA also supports research in animal health that uses nano approaches to develop biosensors that can detect avian influenza virus."

-**Sonny Ramaswamy**, U.S. Department of Agriculture, National Institute of Food and Agriculture

The next presentation, "The Energy Biosciences Institute: A New Chapter in University-Industry Relationships," was given by **Chris Somerville,** who directs the Energy Biosciences Institute (EBI), which was established at the University of California, Berkeley, with a $350 million, 10-year award from BP. Controversial when it was first created, EBI is now in its seventh year. Its mandate is simple: explore the application of modern biology to the energy sector—a rather beautiful mandate, commented Somerville. EBI began by interpreting that mandate as exploring cellulosic fuels and has also pursued research on corrosion and new lubricants. EBI involves the University of Illinois through a very productive partnership, said Somerville. The Institute is mission-oriented but has a 10-year horizon and requires all scientists who work for EBI to be located in its physical buildings.

EBI is at arm's length from BP's business unit. Somerville meets with BP six times a year. The Institute is ultimately governed by four senior representatives from BP and four principals from the universities and Lawrence Berkeley Lab. BP has the power to fire EBI's director, but it has no line item control over the budget. UC Berkeley would not allow line item control because of faculty concerns that the company would cancel types of research that were perceived as potentially unfavorable to its business. "Our priorities are fairly simple," said Somerville, "to understand and improve the environmental and societal impacts of existing and proposed bioenergy industries, to reduce the price of bioenergy, and to look for additional products and processes, including in some cases, in fossil fuel recovery."

EBI has faculty from 17 different academic departments, about 300 people altogether. Chemical engineering, chemistry, microbiology, biochemistry, and cell and molecular biology account for about three-quarters of the people, but there are also faculty involved from economics, law, and politics. EBI's main deliverable is strategic insight, Somerville stated. He went on to explain that a large organization like BP, especially one in transition from traditional energy technologies toward greener and more renewable ones, can find it challenging to understand what's valuable and to see opportunities.

One thing that has contributed to EBI's success is the co-location of research groups. Forcing people to come into the same space has led to the kind of hallway conversations that purportedly happened at Bell Labs.

"What we've just heard may be the ideal arrangement to catalyze interactions between academia and industry, and if it weren't for the cost, we would probably see a lot more of it," said the next presenter, **Steve Briggs,** a plant scientist and professor of cell and developmental biology at the University of California, San Diego. Briggs offered a presentation on approaches he thought might be more applicable to a broader range of university-industry relationships.

Within biology, matching genes with traits has been the main challenge for the past 35 years. Over those 35 years, biology has converged periodically with other disciplines to give rise to molecular genetics, genomics, and systems biology. All of these different fields and approaches, for the most part, come back to the same question: What gives rise to traits? As soon as it was possible to match genes with traits—which was an obvious basic science goal—it was instantly an industrial goal. Once researchers knew the genes that conferred a trait, industry could develop a drug for it, use it in plant breeding or the development of pesticides, fuels, chemicals, or foods. So, the emergence of molecular genetics inspired academia and industry to work together, according to Briggs.

Once industry got involved, they created large-scale, robust resources that could accelerate this process of matching genes with traits, but most of these were kept as company secrets. At the time, in the early 1980s, Briggs had joined Pioneer and, from his perspective, these resources were underutilized within companies and did not exist in academia. Briggs challenged the audience to consider the idea of sharing risk; each party—a company and a university lab—funds its own part in a research project, and both sides drive the project to come up with something that both parties view as valuable and that would reward them in their own sphere. For example, publications and more grants for the academics, product possibilities for the company.

Briggs explained how he has put this concept into practice. First, he helped in establishing a collaborative relationship between Pioneer and Cold Spring Harbor Laboratory with the goal of identifying traits that were important for plant breeding and production in farmers' fields. This collaboration was successful for both institutions.

Novartis then asked Briggs to help them catch up in the area of molecular genomics and they started a new institute, Torrey Mesa Research Institute (TMRI), sponsored by the Novartis Foundation. The idea was to build platforms for genomics to match genes with traits in a more comprehensive way and also to partner with academia. Briggs chose to collaborate with UC Berkeley. Novartis provided unrestricted money to the university, participation by faculty was voluntary, and grants were allocated by a joint committee. This provided the university not only with money but also with access to genome data and the opportunity to collaborate with scientists at Novartis. Novartis, meanwhile, got the chance to collaborate with UC Berkeley scientists and the right to license some of the discoveries.

There was controversy around the collaboration—including criticism from humanist faculty and the editors of *Nature*—but the collaboration went on and was strong. Briggs considered the collaboration successful. In closing, he emphasized the point that if universities could invite collaboration and eliminate the barrier that tells industry "you need to not only pay your costs but also ours," and instead have each party pay their own expenses, it could really benefit universities as well as industry.

Next, **Richard Klavans,** founder of SciTech Strategies Inc., spoke about "Mapping the Convergence and Emergence of Scientific Fields." A map of science is basically a visualization of the problems people investigate based on the literature, Klavans explained. Maps have usually been generated based on discipline, using journal clusters. He and his colleagues are working on developing better maps of science. One way they are doing so is by basing their maps not on discipline/journal clusters but on more expansive key word searches, which makes a huge difference. Instead of 500 disciplines, it uses 250,000 paradigms, as Kuhn originally used the term, said Klavans. (See Kuhn's definition of paradigm on page 2.)

Mapping based on documents is an extremely accurate way to identify an institution's or a country's strengths, said Klavans. He and his colleagues have also used mapping to identify emergent areas—those that are expected to grow very rapidly—and they found that only 125 out of 156,000 topics (less than 0.1 percent) are actually emergent. They also use maps to identify areas of convergence, which means multiple disciplines working on a major research topic. As an example, he explained how he mapped sustainability. For sustainability, over 28,000 documents clustered in 10 areas on the map. The areas included public policy, climate change, economic growth, and education, among others.

Klavans said that his goal is to be able to quantitatively analyze a portfolio of research activities. Science mapping will show what is happening, but it won't indicate why it is happening. To answer that question, he and his colleagues started to map the vision and mission statements of nonprofit organizations. "Convergence is about starting with what the mission is," said Klavans. He showed a map of 100,000 mission statements mapped to areas such as "education," "civics," "community," and "caring for disease and disability." Maps such as these are a window into what foundations care about, he noted in conclusion.

The workshop's final presentation was offered by **Robert Nerem** of the Georgia Institute of Technology, who spoke on "Fostering Convergence: Challenges and Lessons Learned." "Research is a people business, and that's important particularly in this world of convergence," said Nerem in opening.

Nerem described Georgia Tech's experience in trying to foster convergent research. The Parker H. Petit Institute for Bioengineering and Bioscience (IBB) was launched in 1995 before the term "convergence" was in use. Georgia Tech decided that, being a late-comer to the world of biology, it needed to create an interdisciplinary institute in order to move ahead. IBB has 12 centers funded by other sources, 11 of which have a combination of engineering and science faculty. Many of the centers also have public policy faculty. In 1999, the IBB moved into a new building, one that was designed to foster interaction. Science and engineering faculty are co-located. Each wing has five to six faculty members from different disciplines as well as students from different disciplines. The building has a café and hosts monthly social events to foster interaction.

In addition, the institute has a grant program that faculty can only access if there are two co-principal investigators, one from science and the other from engineering.

HOW IS CONVERGENCE CREATED?

"Convergence is not just about working with other people. It is about harnessing the strengths from multiple science and research disciplines, processes, and solutions to accelerate innovation."

-**Melvin Greer**, Lockheed Martin

"In Georgia Tech's Institute for Bioengineering and Bioscience, the science and engineering faculty are co-located. The building for the institute uses an open laboratory concept, minimizing the use of walls and integrating the offices of lab members from different groups."

-**Robert Nerem**, Georgia, Institute of Technology

The building uses an open laboratory concept, minimizes use of walls, and integrates the offices of lab members from different groups. A lot of the interaction between the sciences and engineering grows from graduate students and postdocs talking together and approaching their faculty members with ideas for collaborative projects. In addition, Georgia Tech's tenure and promotion policy uses a first-level committee made up of the three to four people on campus who are best suited to evaluate the candidate. Not requiring the committee members to come from a specific department helps ensure that those working in interdisciplinary areas get fairly evaluated.

Nerem explained some of the lessons learned. He suggested that it takes a combination of faculty and administrative leadership to make something happen. The absence of either one can inhibit progress. Senior faculty members, especially department chairs, tend to be territorial whereas young faculty and students are not. Moreover, Nerem discussed how the reward system for faculty, including promotion and tenure, must encourage convergent, interdisciplinary research. A successful interdisciplinary institute must balance the needs of the institute with the needs of the departments and participating faculty.

He closed by identifying questions and challenges raised by the prospect of shifting toward convergent research. Some of the questions raised included: How can academic leadership alter the culture to make it more conducive to convergence? If physical co-location is impossible, how do institutions encourage "chance" meetings? And, over the next century, will convergence have any influence on the disciplinary structure of academic institutions?

Planning Committee for Convergence: Optimizing Cross-Sector and Interdisciplinary Partnerships: Amanda Arnold (Chair), Texas A&M University; **Melvin Greer**, Lockheed Martin Corporation; **Catherine E. Woteki**, U.S. Department of Agriculture.

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DISCLAIMER: This meeting summary has been prepared by Sara Frueh as a factual summary of what occurred at the meeting. The committee's role was limited to planning the meeting. The statements made are those of the author or individual meeting participants and do not necessarily represent the views of all meeting participants, the planning committee, GUIRR, or the National Academies.

The summary was reviewed in draft form by Alan Rebar, Purdue University and Joseph DeSimone, University of North Carolina, to ensure that it meets institutional standards for quality and objectivity. The review comments and draft manuscript remain confidential to protect the integrity of the process.

About the Government-University-Industry Research Roundtable (GUIRR)

GUIRR's formal mission is to convene senior-most representatives from government, universities, and industry to define and explore critical issues related to the national and global science and technology agenda that are of shared interest; to frame the next critical question stemming from current debate and analysis; and to incubate activities of on-going value to the stakeholders. The forum is designed to facilitate candid dialogue among participants, foster self-implementing activities, and, where appropriate, carry awareness of consequences to the wider public.

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