President's Council of Advisors on Science and Technology (PCAST)
Public Meeting Transcript
September 19, 2014

Welcome

>> John Holdren: Good morning. It is 8:45, our appointed starting time, so let me welcome the members of PCAST, the members of the Office of Science and Technology Policy staff who work with PCAST, and who have joined us here. Let me also thank the members of the wider Science and Technology community who've joined us for this public PCAST meeting. And let me thank those who have joined us in the live streaming of this event on the web. We have a busy agenda, as always, this morning. We're going to be talking about educational information technology, briefly an update, we're going to talk about advanced manufacturing and the report of the task force the Advanced Manufacturing Partnership 2.0. We're going to have some very interesting presentations looking into the further future with alternative visions of where science and technology may be taking us by three very distinguished scholars who think about the future in interesting and systematic ways. We will be hearing from three leaders of the biomedical science community on a set of challenges facing that community, and we will not today be having a public comment, not because we don't love public comment but because we did not receive any at this particular meeting. I want to acknowledge, because it is her last meeting with PCAST, the extraordinary service of Shirley Ann Jackson. The President has asked Shirley Ann to join the President's Intelligence Advisory Board. Members may not serve on two presidential advisory boards at one time, and since it is the President's wish that Shirley's services be applied to the Intelligence Advisory Board, she will be leaving us and joining them. Shirley has been an energetic, enthusiastic, and effective member of PCAST from its very beginning, and Shirley, I just want to recognize you publicly at this meeting for your extraordinary service. [Applause]

>> John Holdren: I also want to welcome to OSTP and to the combined community of OSTP and PCAST our new Chief Technology Officer, Megan Smith, who is at the end of the table there. She is the third Chief Technology Officer that the United States Government has had. She is the first woman to hold the position of Chief Technology Officer, and she brings an extraordinary background and a remarkable penchant for generating creative, innovative ideas to this job. We look forward, all of us, to working very closely with Megan in that capacity. Thank you, Megan, for coming onboard. I want also to comment on an extraordinary release from the Administration yesterday on antibiotic resistance, in which this group, PCAST, played a major role. President Obama and his Administration have been aware from the beginning that the rise

of antibiotic resistance, antibiotic resistant bacteria especially, represents a serious domestic and international challenge. The administration has been actively engaged in addressing that threat. Late last year the President requested a thorough review of what the United States Government is doing to address the threat and he asked PCAST, he asked this group, to produce a report outlining practical actions that the Federal government could take to combat antibiotic resistant bacteria, and directed U.S. departments and agencies to identify priorities and actionable recommendations, and the result of all of that was released yesterday. Yesterday President Obama signed an executive order, which was released yesterday, directing key federal departments and agencies to take a series of specific actions. The Administration also released yesterday the product of the interagency effort to develop a strategy called the National Strategy on Combating Antibiotic Resistant Bacteria. The Administration released our PCAST report on that topic, and it announced a $20 million prize co sponsored by the National Institutes of Health and the Bio Defense Advance Research and Development Authority to encourage the development of rapid point of care diagnostic tests that healthcare providers could use to identify highly resistant bacterial infections. I think taken together that Executive Order, the National Strategy, and the PCAST report, are going to significantly help the Federal government contribute to curbing the rise of antibiotic resistant bacteria, potentially saving thousands of lives. So I'm very happy to see that that release yesterday has led to a lot of coverage, both in the electronic media and the print media today, and again, I'm grateful to the members of PCAST who contributed to that very thorough PCAST report on the topic, which has helped shape the Administration's stance on the issue. With that, I'm going to turn the microphone over to my co chair, Dr. Eric Lander, who will lead us through the next items on the agenda. Eric.

>> Eric Lander: Great. Welcome, everybody. I just want to continue to thank the PCAST for the extraordinary work that has gone on behind all of the reports that have just been released, and that we'll be discussing today, or just approved that we will discuss today that we will bring forward for approval today. It's still been a very active period for the PCAST. Thank you to everybody, and I want to welcome everybody who is watching us on the web, or who will be watching us later today, or sometime in the next century, looking back on the PCAST. So we're grateful to be connected to everyone now and in the future I raise that because one of our topics is actually going to be looking ahead at science and technology in the future, and so we're mindful of that. We'll turn to that in our 10 o'clock session.

Educational Technology Discussion

>>Eric Lander: First, we're going to turn to a letter report that the PCAST has already discussed and approved on a phone call. Sometimes the PCAST meets by phone calls with those telephonic meetings announced in the Federal Register. We held such a meeting on August 28th, and discussed one in what has been a series of reports on education. This is on the topic of education and information technology. Since this report has already been approved in a public session, we're not going to have as lengthy a discussion about it here because it was discussed there, but I am going to turn to my colleague, Craig Mundie, who is going to, in this public meeting, tell us a bit more about that report. The report as I understand is in the final editing process and we expect to have it released as soon as that editing is done. Craig.

>> Craig Mundie: Thank, Eric. We spent about a year working on this issue and convened lots of subject matter experts on it. Fundamentally, the issue that we were contemplating is what the impact is of technological change on the future of employment in the United States, particularly in the mid skill band. You know, our concern is that over time the this mid skill environment is going to find an increasing requirement for technological capability, even in jobs that historically haven't required much, and that there today also is a mismatch of increasing scale between the way in which the educational systems are preparing people for that, the regularity with which updates occur or don't occur at all, and the steady change in the environment in terms of what these skill sets are. The reason we think this is critical to focus on is that today about 48% of all the employment in the United States is in this middle skill category, and we define that as jobs that require some kind of capability that is beyond high school education, but less than a four year baccalaureate degree. So associates degrees, vocational certificates, significant on the job training all would qualify people for mid skill historically. And our view is that the requirements for this are going to increase, and we want to be sure that the country has a strategy broadly because it deals with such a high proportion of all the people in the country who work. In order to do this, we think several things are going to have to happen. One, we're going to have to make it easier for people to find information about what available jobs are, and what kind of training programs will be available to them in order to prepare them for those jobs. Second, we need to foster better kind of connections between the training institutions, the industries that are going to provide the employment, and try to shorten that cycle. Today many of these training programs don't evolve at a high rate, and yet the underlying job requirements are evolving at a rapid rate. And so we'd like to improve the linkage there in order to make that match better. And then we need to find ways to help employers identify the talent to fill those jobs. We think that this may increase mobility for people in the United States. Today we don't see, if you will, mass migrations as we saw in decades past, for example, with the emergence of the auto industry, literally millions of Americans moved into Detroit and surrounding areas because it was clear that there were a large set of jobs in this manufacturing

environment. It is harder to see that kind of mass opportunity today, and yet the technology should facilitate that. We'd like to see that happen as well. In order to do that, we envision and talk in the report about a triangular relationship or three sided relationship between the workers who have employment perhaps, or who want to improve their employment position or those who are seeking work. The employers, who are rapidly continuing to grow, particularly in the small and medium size companies, and the trainers. Today in the high skill environment, we already see the marketplace providing this kind of matching capability with high skill web systems. But those are a bit of an easier problem because you're taking people who spent a great deal of time and money on becoming educated, they have credentials, for example, diplomas that tend to serve as a proxy for employers to determine whether or not they may have the training or skills necessary, and so it is sort of a two party matching that's already beginning to happen. But as we think downstream in this mid skill area, we don't think that people have these type of readily identifiable proxy credentials, and because many of the companies are smaller in scale, they may not have the sophistication to advertise or use these high technology mechanisms to fill these jobs in the future. And we also see a growing requirement for a steady upgrade of the skills of the employers, of the employees rather, and as a result we need to find some way to get the training capabilities, whether they're conventional, educational establishments, or in fact apprenticeships or other mechanisms brought online more, and then link together using these technological means. So to some extent, we think that what this results in is a redefinition of the path that people pursue toward the American dream and the goal of a good employment over their lifetime. So one of the things that we think will happen is that people will increasingly face a question after they have finished high school about whether they specifically want to go on to a two year or four year type of conventional education, or whether in fact they want to start to focus their educational and training activities in more narrowly defined ways, but ways that are specifically important to meeting job opportunities. And so apprenticeships, for profit academies, and in fact company based academies that provide training, all may be more important in the future in terms of creating this optimal match between the investment of time and money, and the preparedness of the person for that employment. And so we also think that particularly the community colleges in the future, may want to alter their curriculum, contemplating that increasingly employers will care less about a sort of generalized curricula, and will care a lot more about very specific preparedness, and we think the community colleges may in fact be able to also provide that kind of certificated training. So we do think this kind of program may emerge, but we are concerned that it may not emerge in a coordinated way with a nationwide scal,e and because such a high percentage of the country's employment will be in this band, we think that the Federal government needs to pay some attention to this question now, not leave this question strictly to chance or the belief that the market may in fact solve all aspects of this. We think there are positive steps that the administration can take using mechanisms that they already have, and we want to make sure that the existing opportunities that employers and trainers provide, you know, are going to be fully advertised to the people who might take them up. So just briefly, the reports resulted in three recommendations. I won't go into the details of them, but broadly, they are in three categories. One, better coordination of related federal efforts across both the education and commerce and standards setting type of activities. The second broad area is in the development of information technology programs that will facilitate this, more about research of the capabilities that need to emerge as opposed to the government operating these systems per se. We also think that an area that government can influence, in fact, relates to these credentials and the forms of certification. Some of the classical ways in which institutes of learning are certified or authorized may need to be expanded in the future and certainly the Federal Government may have some influence on that. Then the third broad area is to encourage the government in fact as a large employer to lead by example, and utilize these mechanisms in concert with those that emerge in the private sector in order to optimize its own employment, and to demonstrate what's possible by using these kind of advanced techniques to match training capabilities and employment opportunities and the specific employee.

>> Eric Lander: Well, thank you for that summary of this report which we, as I just repeat, have publicly discussed and approved. I don't know if any other members of the PCAST wanted to make further some comment on that, but I think Jim Gates does.

>> James Gates: Thank you, and thank you Craig for reviewing the work. I think it is important to emphasize for everyone who is listening in that this is not just about IT workers, that in fact when Craig mentioned middle skills, it's very broad, and this is a mistake I have seen made already in discussing the output of this report, so it's not just about IT.

>> Craig Mundie: Yes, but it is using IT to help all workers, workers who, sorry, all mid-skilled workers, there that's right. So when we talk about this, we sometimes call it our ED/IT report. it's not about IT for education or something like that, it's not about the jobs for IT workers. It is really about making sure that these mid skill workers can take advantage of these great matching opportunities that are arising at other ends of the employment market. Great, thank you for emphasizing that point that has actually not always been clear. I think it is actually clear in the report, and when it comes out, it will be clear.

Advanced Manufacturing Partnership 2.0 Discussion

>>Eric Lander: I want to turn to our second topic, which is a set of recommendations that are ripe for a discussion and for consideration for approval by the PCAST. Some years ago, we issued a report on advanced manufacturing. That report contained amongst other recommendations, a recommendation to create an advanced manufacturing partnership. That recommendation was taken up vigorously by the administration, which created advanced manufacturing partnership and it has already been very productive over the past couple of years. It is now in its second version and 2.0, and we have before us today a set of recommendations for consideration that come from the AMP 2.0 working group, and Shirley Ann Jackson has been part of the structure that oversees this activity, and is going to report to us on those recommendations, and all the input into those recommendations.

>> Shirley Ann Jackson: Thank you, Eric. As we all know, the whole focus here is on preserving and indeed enhancing U.S. manufacturing competitiveness, and the U.S. for over 100 years has been a leading producer of manufactured goods. And that has been very important and the reason it is of interest to PCAST is that manufacturing drives knowledge production, and innovation by in fact supporting in the U.S. two thirds of private sector research and development, and by employing the vast majority of U.S. scientists, engineers and technicians who invent and produce new products. And so our strengths in manufacturing innovation and related technologies that have sustained American leadership in manufacturing are under threat, both because of a shrinkage here, and new and growing competition abroad. So we're at kind of an inflection point, but let me build on what Eric has said in this way. Advanced manufacturing has been essentially part of the history of PCAST, almost since the beginning of this PCAST, and it was an original report issued in 2011 that did call for creating public/private partnerships to support research and scale-up of certain manufacturing technologies, including the use of shared infrastructure. And so there was an advanced manufacturing partnership that grew out of that, that was chaired by Susan Hockfield, who was the then President of MIT, and Andrew Liveris, the Chairman and CEO of Dow Chemical. And the original report of the Amp group issued in 2012 called for sustaining investments in science, technology, and innovation, and one mechanism that was explicitly recommended was to establish a national network of manufacturing innovation institutes, which would be a set of public/private partnerships to build shared infrastructure, and to help advance U.S. leadership in emerging technologies. And that's still something that would require legislation, but there were some early manufacturing innovation institutes created. It also called for upgrading community college workforce training programs and tapping the skills of veterans, and in an interesting way, I think, links to the

discussion we just heard, that Craig Mundie led. And finally, it called for improving the business climate for manufacturing through a tax regulatory energy and other policies. And so once that report was issued, people got started in various ways, including these manufacturing innovation institutes and then there was a re-chartering of the original advanced manufacturing partnership, which we refer to as AMP 2.0. That partnership was co chaired by Rafael Reif, the President of MIT, and again Andrew Liveris, who is the Chairman and CEO of Dow Chemical. And so it actually has worked over the last year with a focus on scaling, promising, manufacturing workforce innovations and partnerships, and on identifying new concrete strategies for securing competitive advantage in transformative emerging technologies. The steering committee for that Amp 2.0, is made up of the Presidents of a number of universities across a broad spectrum, including a major research university. It also includes the CEOs of a number of major enterprises across a spectrum, and also has labor leadership involved, as well. And so out of that work, a set of recommendations have been developed based on three foci, or three pillars that were established two years ago to enable innovation, secure the talent pipeline and improve the business climate. And so the idea was to carry out the vision set out in the original 2012 AMP report, but to particularly layout a vision for the private sector and how it intersects with government and to recommend pathways to generate, again, future innovation and critical emerging technologies. And so it has done its work through several mechanisms. There were a number of working groups focused across the three pillars, as well as once focusing on improving the image of manufacturing, and there were a number of outreach events that were held, and through five regional workshops since the beginning of the year in different parts of the country, but particularly focusing in the Midwest and the Northeast and the South, and they each were hosted by universities in partnership with corporate partners. And so the one in Detroit, I would call your attention to, which is the most recent one, but it was important because of what has happened in Detroit and with manufacturing, there and now what many people feel is a renaissance. So, let me walk through the recommendations, which are grouped according to the three pillars. With respect to enabling innovation, the recommendation is to establish a national strategy in emerging manufacturing technologies, so there is a manufacturing strategy that has been laid out. This has to do with a manufacturing technology strategy, that with a specific national vision, and a set of coordinated activities across the private and public sectors, and covering all stages of technology development, and you'll see a little bit more about this as we go down. And so this includes prioritizing some manufacturing technology areas of national interest, leveraging that process, a process developed by the advanced manufacturing partnership, and then focusing on manufacturing a portfolio of advanced technology activities. And so that how would this be carried out? There is a recommendation to create an advanced manufacturing advisory consortium that would specifically be a vehicle for providing coordinated private sector input on what the R&D priority should be in technologies for advanced manufacturing. The third recommendation gets to be a little more specific, and it talks about creating essentially an end-to-end innovation pipeline to have an R&D infrastructure, which would complement the manufacturing innovation institutes, which are those institutes, I think there are four that have already been created, that would ultimately be part of this national network for manufacturing innovation. But the idea is to bolt things on at the beginning having to do with manufacturing centers of excellence that would be at much earlier stages relative to more of an R&D focus, and then at the later stage having manufacturing technology test beds, but ones that would particularly support manufacturing at a different stage of maturity, but especially organized to help small and medium sized enterprises to benefit from investments made. The fourth, which has to do with processes and standards, but particularly focusing on interoperability of manufacturing technologies on the exchange of materials and manufacturing process information, and certification of cyber security processes for developers of systems, and in a few minutes I'm going to ask my colleague, Craig Mundie, to particularly comment in this area. But the feeling was that this was particularly important. Craig, maybe you might want to make a few illuminating comments here.

>> Craig Mundie: Yeah, I think over many years the evolution of information technology systems has gone from a time where the focus tended to be on standardization or the plug replacement of one system for another system because in fact that was the only way that people could readily move from one generation of technology or one vendor to another. But as the interoperability has increased in importance, and where the internet, for example, has demonstrated, that it becomes far more important to have protocols that allow us to exchange systems, exchange information between dissimilar systems. We begin to realize that the whole process of getting the standards or getting to these common bases of exchange, have a different evolution, in particular the in the standard world related to software, generally the products emerge first, and then there is generally acceptance of them, and then in some kind of de facto standardization process. That's quite different than what happens now in the world of physical things, so whether it's plugs or radio frequencies or other things like that. There, to get the market to move, you often want to agree a priori on how the interactions will take place, and then the market move. So in the case here where we have all of these things present, we have the need, for example, with physical sensors or other aspects of manufacturing, to have some commonality, we may want to see some type of a priority standardization, but as it relates to interoperability, which is really increasingly dominated by software capabilities, we expect that the focus on common data formats, common ways of describing through metadata how the system works, and what the form of the data is, and developing common ways of sending messages back and forth between these systems, has been demonstrated to be

effective at scale in the internet and other environments and we think those same concepts should be used here.

>> Shirley Ann Jackson: Thank you, Great. So this manufacturing, advanced manufacturing innovation ecosystem that includes these manufacturing centers of excellence, and the manufacturing technology test beds, are all built around having this national network for manufacturing innovations anchored by these manufacturing innovation institutes. And so it is very important that there be an appropriate governance structure for all of this, so the Amp 2.0 steering committee is recommending the creation through the National Economic Council and through the Office of Science and Technology Policy, as well as the implementing agencies and departments governance structure, to ensure return on investment by the many stakeholders. That would include the input from the various agencies, as well as the private sector from labor and academia. So let me try to articulate that a little bit differently. In the end, this whole infrastructure, this whole ecosystem, is going to play through different Cabinet departments and agencies, and that is what is meant by the implementing agencies and departments. But how all of that interleaves, given the different agencies and departments will focus in different areas, is something that one has to make sure works well, and so the recommendation is that through the NEC and the OSTP, working with these implementing entities, that there is this governance structure that has a big focus on return on investment. The second pillar having to do with securing the talent pipeline, starts with the idea of having people understand that there are good careers to be had in manufacturing. To change the image of manufacturing as being dirty, you know, some people say not so intelligent, etcetera, but with the advent of advanced manufacturing, it is requires high end skills and these kinds of skills that Craig talked about earlier, and then, you know, there's an argument to specifically support the efforts that are built around the National Manufacturing Day to showcase what today's manufacturing is and what careers in manufacturing would be. But then, one also needs to be able to incent, and this is recommendation seven, private investment in the implementation of a system of nationally recognized, importantly portable, and then stackable skill certifications that employers then can utilize in hiring and promotion by having them, by having the government provide some additional funds that are built on investments through the Department of Labor and the Department of Education Trade Adjustment Assistance Community College and Career Training Program. And this is something that could very easily build into the other efforts that are focused in the community college arena. It's also important to do the kind of thing that support the kind of thing that Craig talked about to in fact make the accredited online training programs eligible for Federal support, for example, through a jobs training program, Federal jobs training programs. And finally, there have been a lot of documents and tool kits and playbooks that have been created through this whole Amp 2.0 process that need to be preserved, curated,

organized, in order to be able to scale and replicate the talent development opportunities, and the recommendation is that this occur through the Manufacturing Institute. And finally, in the arena of improving the business climate, the recommendation is to leverage, you know, what's already going on at Federal and State levels, already going on through industry and other private intermediary organizations, to improve the information flow about technologies, about markets, about supply chains, but particularly focusing on SME, small and medium sized enterprises or manufacturers. And then finally, to reduce the risk associated with the scale up, the use and scale up of advanced manufacturing technologies that improve access to capital needs to occur, and the recommendation is the creation of a public/private investment fund for scale up. Of course, always improving information flow, among the partners, government and manufacturers, and then, where appropriate, to use tax incentives to foster manufacturing investments. In certain cases, the recommendations are very direct in saying where the implementation steps should be, in others, there's a recommendation that, a recognition that some of this will play out through the various government processes, including the budget processes. And so there is an undergirding recommendation that says that the National Economic Council and the Office of Science and Technology Policy, the steering committee says within 60 days, should submit to the President a set of recommendations that specify first what the ongoing role of the Executive Office of the President would be in coordinating the Federal Government's advanced manufacturing activities. And secondly, that lays out clear roles and responsibilities for the various Federal agencies and other Federal bodies in implementing the overall recommendations of the steering committee. And so, with that, before there's any call for a vote, I would open the floor, Eric, if that's appropriate, to any comments or questions.

>> Eric Lander: As is our pattern on PCAST that people put up their flags when they wish to comment or question. I see Maxine, Bill and Dan Schrag in that order.

>> Maxine Savitz: Shirley, I want to thank you, thank the steering group and the working group for the hard work you have done. I have more of a comment than a real question, and it's nice to see this sort of continues things that started on AMP 1 and will be continuing, and refer to the recommendation one of doing the national strategy, the national manufacturing technology strategy, that we'll see in the report that over the last couple years, they've actually done three pilot technology strategies on advanced sensing, visualization, and informatics and materials, so they have a basis that they'll be able then to develop the other areas. I think that should be able to make a lot of progress and tying it to the centers, to the manufacturing institutes, will lead to a good continuum that and things happen in an interactive way, not linear, so that I think that's really good use of the three pillars.

>> Shirley Ann Jackson: Right. Thank you, actually you're right. Those three technology focus areas, interestingly enough, in many ways link directly to PCAST's origin definition of what advanced manufacturing is, and so these are really the undergirding technology areas. Right. Thanks.

>> William Press: Thanks, Shirley for such a excuse me, such a clear introduction to this. As I understand it, there were also the sub- working group prepared reports that informed the report and hence the recommendations that we're approving today, and although those sub-working group reports don't have the status finally of being approved PCAST report, my question is, they contain a lot of valuable stuff, will they also be made public and available to inform the whole public discussion of this?

>> Shirley Ann Jackson: Yes, that is the intent, and you already have the private sector working, other groups working to move along. There are a number of activities that have already been underway that I could take up the morning to describe. And so those will be released publicly. They also, that is also why there was the call for this curation focus to be able to put all of these, not just the tool kits, but to be able to put all of this together in a coherent way.

>> John Holdren: That is great. Dan.

>> Daniel Schrag: Thank you. Shirley, you know, I recall our very first PCAST meeting where you emphasized the importance of thinking hard about manufacturing in this country, right away in the very beginning, and you really championed this all the way through and it's very exciting to see how it's evolved, and thank you for being the PCAST member that's kind of shepherded this process through. I have a question that relates a little bit to what Bill asked, which is, it's clear that the leaders of Amp 2.0 have done an enormous effort in reaching out to the manufacturing community. Could you give us a little bit more of a sense of those tendrils, because it seems to me that in terms of the process that may pay dividends, even apart from these recommendations, the kind of fabric that this activity and this planning activity has created may be an important part of the benefits from this whole effort.

>> Shirley Ann Jackson: Right. So I mentioned the regional workshops that had occurred, for instance, this is just one example. And these were organized by the Advanced Manufacturing National Program Office that emanates out of the Department of Commerce. And each one of those workshops had a slightly different focus, but we had one in upstate New York, and so for instance, the focus there was on what sorts of barriers to implementing technologies, what kinds of things could occur at the state level, vis-a-vis the business climate and changes with that, and then what kind of things motivate the public and private sector to come together, and in looking specifically at the role of universities. So each one had a different, slightly different focus.

>> Eric Lander: I was just going to ask one or two things if I could, since there are no flags up. I very much like this notion of the campaign to spread the word about what is happening with manufacturing today and I was wondering, although I know this goes beyond the recommendations per se, do you have a sense, Shirley, of whether that view of manufacturing, which I think we understand has been changing, and many of the leaders in both academia and industry understand this has been changing. How fully is the public really gotten to understand, it wasn't so long ago that everyone was being told that manufacturing in the United States was dead. It was leaving, it was all about low ages elsewhere. Of course in the PCAST reports years ago we pointed out what the real problem with that was, that there was an entire rich end of high end manufacturing that wasn't about low wages, but good wage jobs, but wages were only one small component of it and it was actually the excellence in the manufacturing that made it a great business, and that was a natural American business. We see more and more of that come back here, and of course, the availability and increasing move toward energy independence in North America also supports that. But I am just curious, how far is that message penetrated? I realize in our conversations I've begun to take it for granted, but tell us a little bit about, you know, this whole renaissance and how far it's penetrated.

>> Shirley Ann Jackson: Well, I think the short answer to your question is it hasn't penetrated far enough. But I think, and as usual, you are way ahead of everybody else, but I think there are three sorts of things that are building against each other. One, you might call them the exogenous factors, the question of the people put under the rubric of energy independence, but the real issue being more abundant energy, particularly with, you know, natural gas, and how that has worked to help take the cost out of manufacturing. But there is a lot more thought about supply chains and security of supply chains, and that security plays out in two different ways, having one having to do with the availability of what one needs, or and of the goods and what it takes to transport things. The other has to do with things that relate to

security. I think a second is a recognition that in key, particularly important and emergent technology areas, it is important to have and preserve a manufacturing presence in the United States as part of an overall innovation ecosystem, and I think that's something that those in the business community can really speak to, and maybe I would ask Michael McQuade say something along that line. But then the third is within universities themselves, see that we have an opportunity to have our students at the highest levels understand the importance of manufacturing, and how what they study in engineering and science is a very important piece of that. Interestingly enough, with the question coming from you, I remember years ago MIT having a particular focus on manufacturing, and a number and so now it's coming around again. I think all of these things have to build on each other and potentiate. But Michael, maybe you might say something.

>> Michael McQuade: Yeah, thank you very much, and I would also commend the group that's shepherded this report through. I think it's a very important report, with a very important set of recommendations. You know, I think we've all talked about this renaissance of high value manufacturing in the U.S., and I think there are two continuums I'd put on the table. One is the continuum of innovation at the basic science level to stuff that gets made and, you know, given for example, our aerospace components and stuff you really want to make in the home country, the ability to rapidly move from fundamental material science to manufacturing manufactured goods is optimized by being able to do that close locale. It is also optimized heavily by the fact that the supply chains associated with that kind of manufacturing are not simple, there are lots and lots of people who contribute to making a jet engine, and the ability to manage that logistics and supply chain of the information content that flows across that is extraordinarily important. There is another continuum, which is the continuum that goes from, relates back to the earlier conversation, entry level worker to highly skilled shop floor worker, numerical control worker, to people who in those jobs pursue additional education, to people who end up being engineers in product development, and that continuum is another parallel to the actual innovation to manufacturing continuum, and I think having that ecosystem geographically located helps a lot.

>> Shirley Ann Jackson: Before we might close this out, I do want to take a moment to first thank some PCAST members, but in particular Michael McQuade and Craig Mundie for helping to, you know, sharpen the focus here, but then I want to acknowledge and recognize and appreciate the very hard work of J.J. Raynor from the NEC, and having to kind of help shepherd this whole thing along. And then of course as always, we would never be anywhere without the PCAST staff, particularly Ashley Predith, and a new intern, Lindsay Gorman and then I always

have to give a shout out to Marjory Blumenthal, who keeps all the trains running on time. I just wanted to say that.

>> Eric Lander: Thank you to you, Shirley. I think it's a great report, great set of recommendations for us to consider here. There was a time when we first started considering this that I think we were dealing with the old fashioned debate about industrial policy, and it's great to have moved so far beyond that, and our first report we said, it is not about industrial policy, it's about innovation policy, it's about creating the conditions that allow innovation to flourish in this rich economy and rich country and rich set of innovators, and I think these sets of recommendations that you're bringing forward for approval really underscore that. They're about workers, they're about the conditions for business, they're about the conditions for technologies flourishing. I think it's a really beautiful demonstration of what innovation policy in this area is about, as distinct from this old notion of picking winners and losers in an industrial policy and I, you know, just occurred to me as I was flipping through it, it's a primer on what the difference between those is. So with that, if there are no more questions, I don't see more flags. I think we're at the point where we are bringing these specific twelve recommendations to the PCAST for a vote of approval. Are there other questions before we would call for such a vote? If there are there are comments? We do have a couple minutes here. Please.

>>Ed Penhoet: I'd like clarification about the tax incentive issues. In recent times across the country, tax has been used on a project specific basis, and there's a very well known case at least in California today of the location of the battery manufacturing for Tesla, for example, where states bid against each other for giving lots of considerations with respect to tax and other things to encourage Tesla to locate its battery manufacturing in their state. So Nevada won that competition, but nevertheless, the question I have about this recommendation is that is the recommendation for tax incentives in the manufacturing meant to be more broadly applied so it could be actually utilized by smaller organizations, etcetera, because in recent years there's been a tendency for tax to be used only for big projects, and sort of specifically allocated for competition really between different areas in the country, and does this the word tax incentive in this context imply a broader tax incentive for the industry as a whole?

>> Shirley Ann Jackson: It does and there is a particular recommend I mean, recognition that small and medium enterprises need to be able to have the benefit of this and so the idea would be if there were tax incentives of various kinds, that it would benefit the mechanisms that in fact provide shared infrastructure and help with the scale up of for these enterprises, because

by definition, those enterprises that are scaling to manufacture vis-a-vis emergent and breakthrough technologies by definition are small. And so yes, it is meant to support them as well. But also to support innovation at the state level in terms of what the states might do.

>> Eric Lander: Gates, your flag is up.

>> James Gates: Yes, I'd like to make a short comment. As observed by our leader, Dr. Holdren, this is Dr. Jackson's last time to be here with us and furthermore as observed earlier by Professor Schrag, from our very first PCAST meeting, Shirley pushed this issue of advanced manufacturing that had to be on our scope, radar, so I think that today's presentation by Dr. Jackson marks a wonderful valedictory address on this point and I just want to compliment her on that. [Applause]

>> Shirley Ann Jackson: Thank you. But let me say this, I think Eric got to it. We had to work our way to that because the issues are not easy and we had Rick Levin helping to keep us clarified on these issues, but I think as PCAST does, when it finally came to a point that was the important point, then it supported it wholeheartedly. So I'm happy.

>> Eric Lander: That is great. I will add my thanks, as well, and my confidence even though Shirley Jackson has been traded to the President's Intelligence Advisory Board, I suspect it is not the last we're going to hear from her on this important subject, and we look forward to the continued direction, Shirley. I think we are ready now to call for a vote to approve these 12, in my opinion, excellent recommendations. If there are no objection, I'm going to call for a vote. Those in favor of approving the recommendations? Any opposed? The vote is unanimous. The recommendations are approved. We'll want to transmit, you've referred to a whole pile of very valuable information that has been generated in reports from the AMP 2.0 group. We want to make sure that all is available and transmitted. So, thank you. I'm going to ask whether my co chair, John Holdren, has any further comments on this, otherwise, it's time for our break before we come back for the future.

>> John Holdren: My only comment is that I thought these were terrific discussions, thank you for your able chairmanship of these sessions and let's take a break.

>>Eric Lander: We will resume at 10 o'clock sharp, which means PCAST members are back a couple minutes before that.

Alternative Visions of Where Science and Technology May Take Us

>> Eric Lander: This is a fun session. Hey, thank you all for coming. Welcome back everybody who is in the room and watching on the web. Or as I said, will be watching on the web in the future. For those people who will be watching on the web, some decades or centuries from now, it will be very amusing because we are going to be talking about alternative visions of where S&T may take us, predictions of the future. And Bill Press, who played a very critical role in organizing this session, and thinking who he could bring to us who would be able to talk about where the world is going and what the future will look like, and be willing to do so knowing full well that this would be available to the future to look back upon, I'm going to ask Bill Press if he would coordinate this session.

>> William Press: Thanks Eric, this is indeed a pleasure. So most of what PCAST does is rightly focused on here and now, it's what can we recommend to the President, it's what can the President do when we began in what we hoped would be eight years, and now in two more years, but hopefully in administrations beyond that. Nevertheless, our charter and our horizon is normally in the single digits of years. At the same time, the subject matter that we're dealing with, that we're trying to make go better for the United States and for the world, that subject matter, being science, technology, and engineering, has a horizon that's unlimited. And sometimes even through the thicket of today's issues, we're able to catch a glimpse of this more distant horizon. You know why do we do all this? It's because we hope it will create a better future, we know it will create a different future, and maybe the actions we can take today are that difference between simply being different and also being better. So with that in mind, we decided to organize this session, in part for PCAST members, but also in part as Eric said, for the people who watch these sessions on the web, and my welcome to those people, also. To bring three very different viewpoints, not all people whose job it is to predict the future, although at least one and a half or two of the people that is their job. Some are people, again at least two who are creating this future and therefore have this kind of vision. So there is not supposed to be any kind of homogeneity in the three presentations we're going to hear. PCAST members, you have the detailed biographies of the three speakers, and I'm not going to

read them all. I'll give just the pneumonic almost descriptions for people on the web so they have a little context, and let me just give all three now and then we'll launch into all three talks. We'll start with Neil Gershenfeld, who is a Professor at MIT, and who directs the Centers for Bits and Atoms which is a center that positions itself almost uniquely right at the interface between the digital world and the physical world, both of which we think have futures. Jill Tarter is the Bernard M. Oliver Chair in SETI Research at the SETI Institute. SETI of course stands for Search for Extraterrestrial Intelligence. Jill has spent almost her almost whole career working on that field, almost uniquely among people in the world, and I guess the only other thing I would say about Jill is her early career was portrayed, was fictionalized by Carl Sagan and portrayed in the movie contact by Jody Foster. She's going to tell us perhaps what she's been doing since she went through that worm hole at the end of the movie. (Laughter) And last, but not least, Peter Schwartz, who is now Senior Vice President with Salesforce.com, but has been known for years and decades as I think a self declared futurist. I think Peter may be the only one of the three who is willing to accept that mantel, but has written many books about the future and how we get there, and has an always interesting perspective. So with that, we'll go in the order from my left to my right, and let's start with Neil.

>> Neil Gershenfeld: Good. I'm delighted to join you in what Jill just described as the "bring in the clowns" session. (Laughter) I'm happy to be one of the clowns. And what I'm going to do is, I don't make predictions about the future, but I make bold predictions about the present. I'll make bold predictions about the present. CBA exists to work the boundary of physical science and computer science, and we created it, because I could never tell the difference, and I believe separating them did a great disservice to both. What we look at is how bits become atoms and atoms becomes bits and today I am going to look, focus in at the manufacturing piece, how data and a computer becomes a thing, five minutes on the science and five minutes on the implications. So one of these doesn't fit. Claude Shannon wrote the best master's thesis at MIT where he invented digital, and he showed by communicating digitally with a linear increase in a code there is an exponential reduction in the error. And that exponential scaling, there is very few exponentials in engineering, that is why we're digital, that revolutionized communication and makes the web stream today. (Inaudible) and a larger group digitized computing, computers for analoging got worse with time. He showed by computing with symbols, a linear increase in the symbols and exponential reduction in the error, and we have super computers. MIT made the first NC mill in 1952, this was under Norbert Wiener Server Mechanism Lab. There was a computer, but the manufacturing process is purely analog. So it doesn't fit because the status in the computer, the physical stuff gets smushed around. Projecting forward, this may be 20 descendants of the 1952 NC Mill, compared to one of my favorite processes, kids building with Lego bricks. With the Lego bricks the matchology comes from the bricks, you don't

need a ruler to place them, which means the kids can make something bigger than themselves. There is a constraint that detects and corrects errors so the tower is more accurate than the motor control of the child. You can detect bricks made from dissimilar materials, and crucially you can disassemble the bricks and use them again and make other stuff. None of that applies to almost any advanced manufacturing, 3D, printing, chip fab, none of that applies, the state is in the computer and not in the material. That is not a new insight, it is 4 billion years old, which is the evolutionary age of the ribosome. It is how proteins are made. Elephants are made one amino acid at a time with geometry coming from local constraints. The error rate in making a protein and a ribosome comes reduction in error rate in replicating DNA in exponential reduction of error and error correction. It is digitizing fabrication, not by the design, but actually by the materials, putting information into the materials themselves. That may sound semantic, but it as important as digitizing communication and computation. A few years ago, CBA ran a meeting with OSTP and a number of Federal agencies who were all doing 3 D printing projects, and the idea of this meeting was to look beyond the transition from subtractive to additive, to analog versus discreet. What I'll talk about is well documented here for the science of fabrication and then this was a follow up event on the biological content. What is emerging is a real science of fabrication by putting codes and computing into materials. To show you what you that looks like, one step in is not rapid prototyping, which you've heard about, a lot about probably, but rapid prototyping of rapid prototyping machines. These are machines that make their own parts, rapid prototyping of rapid prototyping machines. To do that, today manufacturing is a bad party game. You design something in a CAD tool, you send it to a geometry engine, that sends it to a CAM path planning tool, that sends it to a communication that sends it to a motion control tool, that sends it to a motor control tool, and bad things happen at every one of those steps. So to do this, you basically have to blow up all that legacy, and let the math talk directly to the motors. But if you are making everything, you can do it. And so there is a very interesting redo of how you build machines, so making the machine as easy to make the machine as the project with the machine, so the machines can change with what you are making. That's first step in. Second step in now is like the Lego bricks, but this is nano Lego matter made out of proteins to make nanostructures. This is micro Lego, these are 3D circuits made out of bricks of electronic materials. These are macro Lego, these are Lego like bricks, but now made out of carbon fiber that are letting us design airplanes that change shape, but these airplanes are much higher performance materials, and they are made not in giant factories the way they are done today, but by robots that crawl around placing little bricks of these discreet materials. And what we found is with little bricks of carbon fiber, you can make significantly higher performance material than the giant ways they are made today and you can build and unbuild them incrementally. They are all the properties like ribosomes, but now for manufacturing, and on the biggest scale, this was a project with NSF, this is work we've been doing with DARPA and NASA, and then with Homeland Security, we've been looking at making geology on demand, landscape scale features for disaster response. So that's discreetizing the materials. Then the step after that is not just discreetizing the material, but programming the materials, and so computer science doesn't describe geometry for computation, you need to sort of redo how software talks to hardware to make programs overlaid on spatial structures. So this is essentially a do over of computer science as geometry to describe programmable materials. Adding all of that quick tour of mainframe computers were followed by mini computers, hobbyists computers, PCs. We're now recreating the history from mainframe of fabrication to mini computers of fabrication, and I'll talk about for the last few minutes to the machines that make machines that are like the hobbyist computers, leading up to the Star Trek replicator as computation embodied in materials as the key insight. We're about here, halfway down this time line. It is about 20 years to get to the replicator at the rate we're going, but the lesson from the slide, the internet was invented on mini computers, not after the PC, and we are at the invent the internet moment.

>> Eric Lander: So we can hold you to that? I was just writing down the really juicy predictions.

>> Neil Gershenfeld: I am seriously accountable for that, I'm in a lot trouble if we don't do it, absolutely. Yes. So we started doing outreach for National Science Foundation to tell people about this, but we thought the machines were much cooler than talking about them, so we started setting up community fab labs which are about the cost and complexity of a mini computer. In 20 years, it is all smushed in one machine. This is fab lab, this one happens to be (inaudible) in Iceland, a little volcanic island, but it is typical, $100k investment, all the technology to create technology, if you want later I'll tell you what is in it, but with all of this stuff, you can make all of this stuff - boats, bicycles, consumer electronics, houses, all made with this. We opened one for NSF, and there's now about 400 and they are doubling every year and a half. They keep doubling as sites joining this growing network. So in that network, I thought that technology was hard, it's hard, but it is zooming along. We know how to do it, what is unexpected is the organizational implications. So you had a compelling report about the need for STEM training, even worse than that is if you don't have an education, the economies diverging, but all of this assumes manufacturing goes in places like this in the upper right. You go somewhere remotely to do a task you don't want to do to get money to buy something you want. What is emerging is a very different business model. Remember, PCs blew up the traditional computing industry, and this is like PCs for manufacturing, this is not toys in the same sense PCs aren't toys for computing. This was one single fab lab in Denmark that counted, they created 300 million dollars in turnover and a 1000 jobs out of one little community lab. In places like this inventing businesses like that, that are an economic engine very different from

traditional manufacturing, and so what is emerging is if anybody can make anything, then new jobs don't come back to the old factories, but there is a very different economy analogous to the impact of computing. In turn for education, you can think about MIT and research, you can think about MIT as main frame. You go there and get processed. You assume it is a scarce resource, so we say no to almost everybody. Just by space, we fit a few thousand people. There is a lot of attention to massive online classes, which I'm not a big fan of, that is like timesharing, there is still a main frame in your terminal connected to it. What in the fab lab network, what we've backed into doing is a program called the Fab Academy where students have peers in work groups and labs with mentors and machines locally, then we connect them globally by giant video conferences and content sharing and all of that. So it is not like Bitnet, it is like the internet. It is an educational network where you can in effect download the campus digital computing and communication plus fabrication, means you can bootstrap and so you can bring the campus to you and once you have this basic set of tools, you can make whatever else you need so it is an educational network. In turn for policy, what has been emerging, it seems like some of you might have participated in, we had a mobile lab at the White House maker fair, which is really shining a light on this isn't just toys, this is really a new kind of economy. This is Barcelona's Mayor. They're putting fab labs in every district in the city, only secondarily for business, the primary reason is for people to produce what they consume. It is a new notion of urban infrastructure, and this is Barcelona's Mayor making a forty year countdown to the city becoming technologically self sufficient, globally connected for knowledge, so data comes in and out but the atoms stay, producing what it makes locally in the city. This is a bill Bill Foster introduced in the House and Senate, to not appropriate but charter as in the national interest and national network of commuted local labs, as a very different notion of national infrastructure. So what you'll see, if background here, the science of fabrication isn't subtractive versus additive, it is codes and programs and materials. It's completely symmetrical with digitizing communication and computation, we're going through the same transformation that is exponentially doubling and it mean fist anybody can make anything anywhere it means how we divide work, play, education, all of those things as separate activity sort of gets turned on the side and do them in the same place at the same time, which means really reinventing whole notion of organizational capacity. Thank you.

>>William Press: Thank you. Whoa! (Laughter) I guess we'll save the questions until the end and then we have a process for doing that, Jill.

>> Jill Tarter: Okay. I'd like to add my thanks for the invitation to be here. Sorry about the clown comment. But I'd like to focus on biological, slightly strange biological vision of 21st century.

We're getting comfortable now with this notion, this tag, but I'd like to mention that in all probability, this is the century that will allow us the exciting potential of encountering and studying biology unrelated to biology here on earth. The opportunities for encountering life beyond earth fall into three categories, we can go discover it, we can search for technology, and we can move it off the planet. For a long time now, a Mars sample return has been kind of holy grail of astrobiologists, but there is just been real very slow progress in reducing the cost of this mission. You just heard how you can do it. All right. If we could shorten the technology transfer time scale for new terrestrial capabilities such that we just heard about, and getting it to space hardened miniaturized versions, then perhaps not long after self driving cars are saving the lives of our teenager, self driving rovers may be performing in situ biological experiments and prescreening the materials, if any to be returned for analysis. So I'm wondering if maybe there shouldn't be a Mars track in the I gym student competitions or maybe that smart rover should just contain one of your synthesizers and a lot of different software. The long history of rock swapping between Mars and Earth means that we have the potential for discovering life as we already know it on the red planet and therefore there are some other regions that we could profitably explore within the solar system. So the watery oceans of Jupiter's large moons, Europa, Ganymede, Calisto, are accessible through the icy coatings and explorations of the subterranean Antarctic lakes today are pioneering the non-contaminating toolsets we might need to do that. Or the ethane methane lakes on Titan, Saturn's moon offered direct access to potential biologically active environments without the need to penetrate kilometers of ice. But you know, there's no free lunch really, but the cryogeysers on the south polar regions of both the moons in Enceladus and Europa, could in fact significantly simplify this whole sample return concept. So in 2004, Stardust chased down a comet (inaudible) and it returned samples that were then successfully scanned by an army of volunteer dusters. All right. They are using Stardust at home to discover candidate inter stellar dust particles. So open source molecular biology and genetics tools could promote a similar crowd search opportunity involving students in the future. In the real return on investment from this whole biomarker study is a second genesis. All right. And like the Mastercard advertisement says, it's priceless. Laboratory synthetic biology is one approach to producing life as we don't yet know it, but discovery elsewhere in our solar system of an independent origin for life actually begins to measure the branching ratios for the experiment of life that are established by physics and chemistry operating in proneus environments. The discovery of second genesis would validate the ubiquity of life beyond earth. And it helps us also to tease apart the necessary from the contingent in our own origin of life on this planet and an alternative biology would provide with us a way of more fully understanding and exploiting the one example that we currently have. So beyond the reach of sample return, we have to rely on absorption spectrum to provide evidence of life on XO planets or moons. The spectrum of earth shine here reflected from our own moon shows the disequilibrium chemistry of oxygen, ozone, and methane that announces the presence of biology on our planet. As yet there is no smoking gun for a bio-signature. Abiotic false positives are possible and appropriate bio-signatures will change over the lifetime of the host body, and spectroscopy cannot be conclusive in the absence of planetary characterization. In the near term JWST may be able to use transmission spectroscopy during XO planet transits of the nearest stars to detect atmospheric constituents. An oxygen dimmer bio-signature in an oxygen rich atmosphere of a terrestrial planet in a habitable zone of a nearby (inaudible) or methane or NO2 in the atmosphere of super earth orbiting an (inaudible), or even industrial pollution, may be in the reach of JWST. But to go beyond the nearest (inaudible) requires direct imaging capabilities and better resolving power. So instruments-to-image terrestrial XO planets run the gamut from $10 million privately funded a few years to multibillion dollar missions decades in the future. And these imaging missions are probably going to lack both the large collecting area and the special resolving power required to detect bio- signatures in the atmospheres of the imaged planets unless we get lucky, and the nearest inhabited planet is very close. So I think the jury is kind of out on the return on investment for bio-signatures, at least the direct return on investment, but indirectly, we've seen a huge explosion of bright young students drawn into science and engineering by challenging and the glamour offered by the prospect of finding habitable and inhabited worlds beyond earth. Now this is my part of the story, right? In searching for techno signatures, what we're doing betting the gain will be in the transmitter and therefore it won't be needed in the receiver. If we look in the right way at the right time and the right place, we could succeed tomorrow. But given the number of places and times and ways to search, it's a really long shot and you know, it's one that is so inexpensive that it is worth including in our search strategy. SETI offers an obvious opportunity for global coordination, collaboration with U.S. leadership. The exploration will grow in power as collecting area and computational capacity continue to increase, and as we develop new ways to mine data collected for other purposes, and as we deploy new search strategies based on technology we haven't yet invented. The Phillip Morrison used to call SETI the archaeology of the future. Any information bearing signal that is detected will tell us about their past, but the fact of a successful detection will tell us that we can have a long future. So at the moment, frequency compression and time compression are the hallmarks used to detect obviously engineered signals. But traditional astronomical observing programs may serendipitously identify other manifestations of distant technology. Recently highly disbursed fast radio bursts have been discovered in large data bases generated by pulsar surveys. While likely these are caused by hugely energetic sources of unknown origin at extra galactic distances, if their spatial distribution turns out to be non-isotropic, these could be deliberately (inaudible) signals from technological civilizations much closer to home. Astro-engineering projects that construct noncircular artifacts that transit a star, or neutrino factories capable of tickling (inaudible) variables or producing neutrinos at higher energies than any known natural sources might be found with big data mining of the data bases being constructed by observatories today. And what we learn from the techno signature approach to search for life beyond earth that we cannot learn from any other approach, is that technological civilizations can be long lived. Some other technology survives for cosmologically significant times, so can we. The return on investment for moving this off this planet is the mitigation against a single point failure. The destination is not the real issue, that will define itself as we proceed. The real issue is to commit to beginning or at least not to impede those who would, and then sustain that commitment. And our youngest generation of scientists and engineers is watching these decisions closely, deciding whether they're going to jump onboard or not. Like Neil's disruptive manufacturing, we should be mindful that this commercial enterprise could rewrite the geopolitical map of the earth. In considering a further horizon, how about a starship, that's a big hairy audacious goal, and the return on investment of this very long term project could be the solutions to some of the 21st century's mega city problems coming from a wide cadre of creative people, problem solving, solvers who are not traditionally involved in space technology or in city planning. You know, this is the stuff of childhood dreams and it's a very sexy STEM magnet for young students that can it can be made gender neutral from the start, and they can build their careers and their futures from their own innovations. A starship has both a replicator and de-constructor, and the lesson of a starship is that recycling has to be perfect. Your take apart as well as put together tools are phenomenal. Trying to get to this perfect recycling will hopefully provide better solutions with fewer unintended consequences than some previous efforts to alleviate big city crisis. Okay. In 1984, there was a problem, a manure crisis in New York City, an obvious solution was to invent radically improved reprocessing technologies. Instead, it turned out to be cheaper or maybe just more profitable to invent a mechanical horse. Now instead of drowning in manure or co2, New York City will be drowning. All right. (Laughter) The manure crisis is often cited as example of innovative, unexpected problem solving to look forward to as the model for solutions to insoluble problems in the current era. I pretty much disagree. Waste is a resource to be reclaimed, not discarded. This is the best approach to obtaining the raw material for those fabulous synthesizers and machines of the future that we just heard about. In the 21st century, we're going to have many megacities with populations over 20 million and I think that we need to treat these megacities like starships, we need to use biomimicry to engineer their defense and the return on investments from activities like the 100 Year Starship is new framework for problem solving and a potential for fewer unintended consequences, and a new ethos of stewardship transmitted to the next generation that has immediate applicability to these terrestrial megacities. Thank you.

>> William Press: Great. Peter.

>> Peter Schwartz: Thank you. First of all, let me say thank you to the committee and also to my colleagues here, both of who are friends and collaborators in other contexts. Half of you are old friends of mine, even shared an office with Ed Penhoet for a while, had the privilege of attending the esteemed university that Shirley Tilghman runs. What I'm about to talk about, a version of the talk I gave to trustees at RPI last spring. In fact, I have to say, Bill mentioned some of my books, I also helped write movies, one of which is a film that many of you will have seen called "Minority Report" in which we tried to create a vision of the future that Steven Spielberg put on the screen, and Neil was part of the committee, the group I put together to work with Spielberg, and I have to say one of the highlights of the meeting was watching Neil explain quantum entanglement to Spielberg. It was quite a show. Okay. May I have the clicker. Thank you. Okay. So when I think about this question, I think about five subsidiary questions that drive my thinking. Science and Technology advance because the tools of science and technology advance from the microscope, to the telescope, to the computer and so on. And so interesting questions, what are the tools of the future that open up new frontiers? New methods, we're seeing new methods in science beginning to develop that are quite significant. Where is the talent going? Where are people investing their lives? Where are we spending our money and finally, what are the interesting questions that drive people's careers and drive them to pursue advances in science and technology. Let me address those very quickly. I think we can make a few key assumptions, basically that we're going to have more information technology embedded everywhere, little bits of intelligence. I'm not one of those people who believes we're about to have big artificial intelligence, but lots of little bits of smarts in many, many places taking the friction out of almost every process. There will be more resources and talent, more, new and better tools. But as in the past, when science and technology were driven heavily by the needs of conflict, now the big challenge driving the world of course is sustainability, water, food, energy, all of that, as well as the human and social dimensions of this. This is I think the single biggest challenge that our civilization faces. I think the clean energy is the single biggest technical challenge we face. If we don't find it, we're screwed. And nothing that is in the laboratory today is likely to be the answer, maybe fusion power, maybe, but that is still a big maybe. If not, then we have a really big problem as a civilizational crisis over the centuries ahead of us. That is the single biggest issue I think we need to be addressing is can we find the answer to clean energy. If the answer is yes, then it is open future. If the answer is no, we have a very big problem. In thinking about the tools, we start thinking about a long list, whether it is the new space telescope that I think you were talking about, Jill, that we need to detect signals in deep space, whether it is things like the large hadron collider, and our ability to operate it at an incredibly small scale. We think about computation, we're moving into an era where again we're not too far from when we can actually begin to think meaningfully about quantum computers. I was down at NASA AMES recently, and they are beginning their first experiments in practical terms with what are the first near quantum computers, and I say near

because it is not quite the d wave computer and so on. So what I'm suggesting is that we're across a wide frontier developing in a large number of new scientific tools that are opening up the frontiers whether a new means sensors, new means of computation, new means for controlling matter, etcetera. In thinking about the methodologies of science, I'm struck by the fact that we actually have new ways of doing science, and among them first of all are understanding complexity. Dan Schrag and I met at a meeting looking at climate change and complexity at Santa Fe Institute where I was trustee for a number of years. Big data is obviously another example of that. The ability today that we have to both gather and process vast amounts of data that are staggering both in numbers and critically lead to the next which is algorithmic discovery which is basically designing algorithms that can look at that great volume of data and find patterns that we would not have found otherwise. So we are literally able to make discoveries the human mind did not conceive of except in setting in motion the sequence that led to that discovery. So we now have actually machines that can make novel discoveries and as a result of machine learning, that process is accelerating rather dramatically. Finally, the methodologies associated with what I think of as bottom's up science. Kick starter science, if you will. Science with thousands, millions of participants engaging, SETI, perhaps the first example of that, lots of people out there wanting to participate because of their passion for the subjects and so on. We're actually moving into an era of new ways of doing science, as well. I think there is a new domain beginning to emerge that is quite significant, we ought to begin to pay attention to. I call basically human systems, I'm not sure what the right word is, but if you think about it, psychology, sociology, almost everything that deals with human beings was largely observational and empirical. You looked at what people did and you had some really brilliant person, a Freud or a Max Weber, who looked at that set of data and said, well here is a pattern that begins to make sense. It was a kind of an intuitive apprehension of an understanding of human behavior. In fact, what we're now beginning to develop are new methodologies that allow us to understand human behavior and in far more rigorous ways. One end is neurobiology, for example. David Eagleman, the neurobiologist at Baylor University created Center for Neurobiology and the Law looking at what the implication of understanding of neurobiology are for human behavior and criminal behavior, what can be fixed, what can't be fixed and so on and profoundly significant. All tools of simulation, new behavioral economics, the abilities to do large scale economic experiments and so on are all moving us into an arena where we can actually do meaningful experiments of the sort that we have only been able to do in the physical and biological sciences before. I think new domain is opening up for consideration of how we explore it. One place where we see this happening, and I'll return to this in a moment, Singapore, doing a number of experiments in a very large scale, and in quite rigorous way because they can do things that many countries can't. That leads me to the next point, which is the talent and the money. One thing we're seeing globally is enormous increase in number of people and the amount of money going into science and technology, and I'll only use the example of one small country, Singapore, where I serve on what is called the Research Innovation and Enterprise Council, chaired by the Prime Minister, five Cabinet Ministers and five outsiders. I've served on it since the beginning as has Clay Christenson, a number of American University presidents, Susan Hockfield, John Hennessey, and others have served on it with me. A number of industrial leaders, the heads of R&D at Exxon, Novartis, etcetera. And in 10 years, we spent $80 billion, and our next budget another incremental 20 billion dollars that we will start allocating in October. And I say this because what is happening therefore is that the enterprise that was overwhelmingly concentrated in the United States and Europe and Russia is now becoming global. To really understand the where things are going to go and where things are coming from, it is no longer adequate to go to MIT, Stanford, Cambridge, etcetera. One has to visit the National Universities of Singapore and elsewhere in the world to see where in fact the real frontiers are beginning to emerge. From my point of view, Singapore represents, I think a really new model, perhaps the only ones that I've seen globally who've have actually been successful in this enterprise of creating a new kind of science and technology foundation. One need only visit the ruins of Sophia Antipolis outside of Nice to see what failure looks like as well. I think you can reasonably predict several things that are going to happen. One is we are going to understand molecular biology much deeper level, going to understand the brain and the mind at a much deeper level in the near future. I think we'll have much smarter machines, but cyber security will remain a big challenge, that is I think we have not solved that problem, and the bad guys are ahead of the good guys on this, and I think it will be a perpetual challenge unless, and I say unless, we can figure out how to build what my colleague and Danny Hillis and several others have argued, my colleague Mark Benioff, we need an Internet 2.0 that is inherently secure. The Internet was created for collaboration, and is very good at that. What it is not very good at is security. We have to put security on the ends of a system designed for openness, and so the challenge is can we redesign the system so it is inherently secure. I think that is where we will end up going. I already mentioned huge systems, sustainable technology. Like Jill, I am quite convinced we'll discover life elsewhere in the universe, the biggest discovery in that respect in recent years is that planets are common, they are not rare. And so we will find some form of life, probably somewhere in the neighborhood, intelligent life is a different question. That is a far bigger challenge. Finding intelligent life in our neighborhood in space and time I think is somewhat less likely, I hope you are right, I really do and I'd like to be on the Starship, I think it is a great idea, let's be clear. I wanted to be an astronaut, my first failure as a futurist was getting the astronaut market wrong back in 1968. Where are big surprises coming from? I think what we've been astonished in physics over the last 20 years by discoveries like entanglement and dark energy. Einstein believed entanglement was his biggest mistake. Turned out he was right. Particles can be entangled. There is something called dark energy overcoming gravity, we don't understand it, that is why we call it dark. We had a real (inaudible), that would be a big surprise. Being able to control molecular biology and cracking the code of DNA in a really deep way, that is a big deal. Do we get fusion power? Do we undertake geo- engineering? These are big questions. I think one of the interesting physics revolutions that could happen, if you think about it, that is that beginning in the middle of the 19th century, we began the electromagnetic era, we began to understand electricity and magnetism, and out of that came not only physics but the vast electrical technologies that drive our civilization today. The one force we do not understand is gravity. Imagine if in the next 25 to 50 years, and there is a lot of work going on, the last force yields to our understanding. We actually understand gravity. Now I don't know whether that means flying cars or not, what I do believe is that it is almost inevitable that somewhere in the next 25 to 50 years we'll develop a meaningful understanding of gravity, with all of the implications for civilization that electromagnetism had in 1850 for the future. We could not imagine our world without that electromagnetic tools. Well, today imagine what it would be like if we had gravity. Finally, the energy issues of flight. The reason we don't have very fast aircraft is energy. The reason it's expensive to go to space is energy. We don't know how to get enough energy to build the vehicles that are necessary for that kind of flight. So that's what I wanted to share. I hope that is of some relevance and look forward to the discussion. Thank you.

>> William Press: Thank you. Now if PCAST members don't have questions on this (laughter) shame on you all. But I see you are not disappointing. I better start a list. Susan, why don't you go first.

>> Susan Graham: I think my question is for Neil, but it may turn out not to be. If it becomes not only easier, but faster to fabricate, then what happens to deployment? How do you what are the social processes and the business processes and so on that separate the good ideas from the garbage, and I mean, we have a notion now already of things going viral, that we have communication that allows information to get out there faster, but what happens in the marketplace once you have this capability?

>> Neil Gershenfeld: So I'd split that into two pieces, one was deployment and one was curation. In the deployment, histories of very great and precise guide. If you look at printing, HP's printer division is in Corvallis, Oregon because they had to hide from Palo Alto, because inkjet printing didn't scale and printing was supposed to scale, but of course a lot of little printers add up to output from one big printer. We have big printers, but the engine for HP is a lot of little printers. If you look at how music, software went from software companies to lots of app development, how music went from labels to lots music development. Mass

manufacturing, big record labels, big software companies haven't disappeared, but what's appeared is new tiers that didn't exist before. This doesn't replace traditional manufacturing, but in the sense it makes the boring things, it makes the things where everybody needs the same thing. This adds new tiers that didn't exist before, it is the deployment. From one thing you can design something and make it many places simultaneously, shipping data and producing on demand, those platforms don't exist, but they are coming. That's replaying that historical script, in one case data becomes sound, in one case it is an app, now it is a thing, it is that script. The second piece I'm really invested in, the curation, in that there is a lot of celebration of do it yourself in the maker movement, and there is a lot of really stupid stuff in the do it yourself in the maker movement where nobody is around to say actually that is a dumb idea, and it has been done before and there is a better way to do it. Projects like the Fab academy have to do with mentoring, how you take just in time and tropic bottom up, but you mentor from things you can do in a day, a week, a month, a year and that involves distribution and much less control, but involves mentoring and curation. It is not commanding control centrally, but building networks that can mentor is something I spend a lot of time on and found is absolutely essential.

>> William Press: Jim Gates.

>> James Gates: Thank you, Bill and thank you to the panelist, nice to see old friends and to hear this wonderful discussion. My question is basically directed towards Peter, but please the rest of the panel, also feel free to weigh in. One of the activities that PCAST undertook in recent times was involvement of discussion of big data and privacy. And even going into that discussion, I must admit one of my concerns was when we have these enhanced abilities to model human behavior to plan based on models, to think about constructing large scale human systems that interact with these models, the thing that occurred to me was that the issue of sustainability and ethics in the context of our human ability to interact with this, is something that was very worrisome and in particular I was reminded that as we, as genomics revolution began, the issue of ethics was actually discussed right at the beginning of the process as opposed to being a later add on, and to me this was a new sort of model to think about the simultaneous development of the ethics around new technologies, and the development of a technologies themselves. And given what I've seen of the ark of how the world's politics has evolved over the last 20 or 30 years, this issue of the sustainability and ethics attached to these new technologies is going to be an enormous driver in terms of disputes, the wide scale adoption and in fact, quite frankly the thing we talk about diverging income in this country, all

this gets wrapped up in this whole issue. I'd like to hear Peter, what your thoughts are about this.

>> Peter Schwartz: There are two fundamentally different, but related questions that come along with that, and you touched on both. One for example is privacy and the other is income distribution question and Bill and I were talking about this beforehand. On the privacy issue, I think it's a rather profound one. But having said that, the truth is that I think when we look at it from a historical perspective, we will look and what I'm about to say is not corporate policy, but it is personal, let me be clear about that, that privacy was an artifact of the 20th century, that privacy did not exist much before the 20th century unless you lived in a remote location, if you lived in a village with other people, everybody knew what you did. If you lived in Japan and little huts with thin walls, you knew what was going on with your neighbors, and you developed a psychological privacy that allowed everyone to have an independent life even though they all knew what was going on. We do now live in the global village. McLuhan was right in that respect, and that in fact the access to knowledge and information that has developed globally will mean we have to rethink what privacy actually means under those circumstances because that knowledge will be, like it or not, available in so many different ways. I have my own mini drone I fly off my terrace. My neighbors, I'm not so sure they love that. You know. Having said that, the point is that I think we're going to have to rethink what we mean by the relationship between people and their technology, and this being one example. The other, the income and equality in the jobs issue is a more difficult one. Here I think it is mostly a matter of time in terms of job creation. We've had a number of essays by Tyler Talon and Robert Gordon saying we've basically exhausted our technological potential and only the inventors of technology at the top will get rich and the rest of us will be impoverished. I think that is a failure of imagination, a complete failure of imagination. I work in a company in an industry that didn't exist 15 years ago, cloud computing. Nobody worked Salesforce.com, in the year 1998. Today there are 15,000 employees in three years time, will be 45,000 employees and we are growing at 37% a year. We have partnered recently with Microsoft in collaboration. This is an industry transforming the world. I believe that these are times when we are reinventing industries and the jobs begin to flow as the other industries are affected by it and transformed by it, the people who will be working in all the Fab Labs that Neil is talking about. The other day I saw the first 3 D printed car from a company called Local Motors, we start reinventing the manufacturing process fundamentally. So in my view, that essentially we are going to be great transitions that we have gone through, that we have gone through from time to time from agriculture to industry and so on with massive dislocations, and it will happen and will not be painless. In the end, there is no end, the next stage in the process will be the creation globally of vast number of jobs in new industries as well as the reinvention of old industries. I think that

concern is real for the moment, but the fundamental concern I think is misplaced in a sense that it represents failure of imagination.

>> William Press: Marc, I think you are next.

>> Marc Kirschner: Thank you Bill. My question is for Neil. Fab Lab is really amazing to watch. You have done a lot of early experimentation. Your article in World Affairs talks about how taking it to cities like Detroit now. If you could experiment more, if you had more support from the private sector, local governments, Federal agencies where do you want to take this? What experimentation do you want to try next?

>> Neil Gershenfeld: Yes. So great question. First of all, it is not me to be clear, I'm a surrogate. This was an accident that went viral, and I'm sort of a stand in for this viral growth. It's not remote. My vision was one lab and that's all I could see. I'm representing this exponential growth. For me, the thing most exciting for me is, I think the scarcest resource untapped on the planet is brain power. MIT fits a few thousand people and the MITs of the world, there's a few thousand maybe of them. We're finding in Arctic villages and African shanty towns and rural Indian farms, precisely the bright inventive creative profile of the kids we find at MIT and so for me the opportunity we're talking about is harvesting a much greater fraction of planet's brain power. What's been limiting is, I'd say organizational capacity in the commons. In the early stages, I had to essentially, choosing my words carefully, sort of hijack some government grants to spend them on infrastructure that made this possible. So there is a lot of technology curation where the materials come in software and workflows, and bills spinning off the foundation and all that is building the capacity, organizational capacity. It is really easy to find the inventive people, and there's orders of magnitude more than we are servicing. It is really easy to find the people that want the benefits from it. What is actually really hard is the organizational innovators who can build the capacity to make this happen. So for example, Chevron recently made a $10 million commitment against the bill not passed, but charters this is a public private partnership to invest in the labs in the communities where is it works, and they're intentionally investing more than the labs need to start to build this organizational capacity. I would pair the opportunities, picking up from Peter, one is using more the planet's brain power, and I put next to that the whole notion of work. If you think about it, I think this last century fiction is you go somewhere from where you live where you don't want to be to do something you don't want to do, making something designed by somebody you don't know for somebody you will never see to get money to come back and get something you want. And what if you could just go to

the get something you want part, and so it's not that it is for free, but there is a lot of assumptions baked into the words job that change but what is limiting is capacity. Investing in the commons. It took a federal investment in the commons that became the internet to let the dot.com era happen. We're at a same point like that and that is why projects like this Barcelona one or this bill, sort of viewing this as infrastructure, infrastructure for invention, not top down billion dollar shiny things far away, but bottom up investment, not by themselves because no one site knows enough to do it, but investing in the network, as a new notion of infrastructure. Everybody wants what comes out, but it is much harder to invest in the infrastructure that make its possible. That is the opportunity. Thanks.

>> William Press: Thanks. I have Dan next.

>> Daniel Schrag: Thanks, I want to ask Jill a question about her discussion of astrobiology. So I look at Mars a little bit differently than the way you talked about it. You seem to be very confident that we are going to likely find life on Mars and I think you talked about exchange between the two planets. My understanding is actually that the only possible time when we could have had earth material go to Mars other than our spaceships is during the early bombardment period where there almost certainly was no life on Earth. So you know it's really a one way transit for meteorites, because of the sun and because of the gravitational field of the earth. So the question really is in looking at life, I'm a little fearful that the justification for exploration of our solar system is based a little bit too much on this on encouraging the public's fascination with finding life because it feels a little bit dishonest to me. The early history of Mars is fascinating, for all sorts of reasons, independent of whether life was ever there. And so I just worry a little bit about feeding this. For example, as you said, we're a long way from figuring out what the bio-signatures of life in extra solar planets really are. Mars has, 1500 parts per million oxygen in the atmosphere, and we know that is not from life, that is from photolysis of carbon dioxide. So the question is, if it really wise in the long run to be quite so encouraging of this focus of discovery of life on other planets, when all the evidence thus far suggests it is probably not there.

>> Jill Tarter: The question is are we just hyping this stuff because the public likes it. First of all, the exchange of material, when I said we might find biology there that we recognized, it would be a scenario where early Mars produced life forms before the Earth did and they traveled from there to Earth, that is energetically the most feasible way. So we're Martians, that is what I meant by that. In terms of are we overselling the potential for life on Mars? I don't think that

you'd get many of the astrobiology community to agree with you. They are certainly, what we're finding is that the ingredients for life are there. What we think is necessary for life is, and has been there. Whether it turned into life, that's really such a key question. It's worth looking for it. And if we are over and I think I do agree with you that we may be overselling the likelihood that we will find it, but it is really a key exploration.

>> William Press: Thanks. Barbara, your flag was up, now it's down. Are you

>> Barbara Schaal: (Inaudible)

>> William Press: Okay. Okay. Then I have Michael next.

>> Michael McQuade: Combination, maybe question and ask for comments from Neil and Jill. I'm interested in sort of state of play and where you project the issue around materials, let's say source materials because if I take Jill's comments, I don't want to talk about raw materials for making things, I want to talk about either raw or reused materials, etcetera. So we do these exercises all the time and we convince ourselves that sort of on a unit basis I can energetically make a part less expensively in an additive manufacturing because I don't have waste and I have the other things, but if you draw a different control boundary, you may get a different answer. When I think about things like sending the minimum mass spacecraft to Mars to make the return vehicle on site, I get into a very complicated question about the energetic cost or the extraction cost or the reuse, where are we? What do we know? Can you comment on that?

>> Neil Gershenfeld: I'll start on Earth. Let me give you a short term and a longer term answer. The short term answer is the microcosm of that is this network of Fab Labs that we have in Arctic villages and rural shanty towns away from supply chains, and what we find is in the short term version, there is a large set of consumables that are easily sourced locally, like wood fibers and then there is a small set of high tech consumables the we have to source globally, like microcontrollers and precision tooling. And so a box the size of this table would supply one of these labs for a few years with the high tech consumables, and all the low tech consumables, there is versions of sources and recycling locally. It is the short term empirical statement. But the longer term research statement is there is no trash in a forest, stuff gets taken apart and

used again. The heart of the ability to do that is hierarchal modularity and biology in the materials. A lot of the discussion of in situ manufacturing has a mental picture of squirting out tubes of toothpaste of regolith. What we are finding the heart of the reuse comes from building hierarchically into the material. The materials not chemically, but structurally contain enough information to take them apart and reuse them again. A lot of different areas we're finding what sounds like hard recycling that is hard because you have under constrained, the problem becomes easy if you build more structure into the materials. By again this transition, not from subtractive to additive, but from analog to discreet in the materials, for me, that's the heart of answering it, and then a lot of these recycling questions become much easier.

>> Michael McQuade: I guess two questions. So the argument by analogy, I mean, there is no trash in a forest, but there are also no supercomputers, right? It's a system designed to make certain things.

>> Neil Gershenfeld: I think around the room you would get debate about that question.

>> Michael McQuade: Okay, maybe a bad choice, but the real question is sort of at what level of complexity on what time scale do you think we can do fundamental manufacturing? Your comment was I got to start with a box, high tech part, somewhere that presupposes they exist, right?

>> Neil Gershenfeld: It's a great question. I don't know if you have seen John Main at DARPA has a really interesting solicitation where he wants to have a program going from nanometers six orders of magnitude essentially by building this hierarchically modularity in decomposition and I think that is right at the edge of the current research questions and what you are asking.

>> William Press: Okay. I'm going to try to keep us on time. So the two last questions will be Craig and Susan. And that will be it. Good. Craig.

>> Craig Mundie: I guess some might argue, I probably would, that over the last 50 or 60 years, computing and its evolution has played a central role in accelerating that, even enumerating

the new forms of doing science all have their basis in that. When I think about the things collectively that you mentioned, Neil and Peter, in biology and nanotechnology and things like that, despite the exponential progress in electronics and computation, those things take us into a realm where the things that have advanced us in particular, modeling and simulation, in order to know what to build, don't appear to be in the cards for classical computers. So Peter mentioned quantum computation, and you know at least some of us think that has sort of started to move from the realm of the not the if, but the when, and in essence, do you think there is enough emphasis on the importance of cracking that code, pardon the pun, to in order to facilitate the use of all these things? If I think about, you know the low level manufacturing, you know, the biological analog to that, the synthesis and new materials which may be key to doing these things, it seems like all that will find computing in a central role again, but not the kind that we know today. So interested in your thoughts.

>> Neil Gershenfeld: If I could start and hand off to Peter. I didn't know Turing or Von Neumann, but I could ask Andy Gleason what Turing thought, and Marvin Minsky what Von Neumann thought, and what I've learned from that is the prevailing model of computation that made Microsoft and others wealthy was really a hack and neither Turing or Von Neumann were proud of it and took it very seriously. It was basically a historical accident that's long overdue to fix. The heart of it is, it enshrined a very unphysical model of computation where computation doesn't have physical resources. Space and time doesn't appear anywhere in the description of computation. As a result, it means our classical models of computation barely scratch the edge .A patch of reality store states takes time to transit, admits interaction, has non-linearity, in computing those are viewed as unrelated resources. So what is adds up to. My colleague Seth Lloyd has done nice calculations showing we're about 10 to the 90 off the available computing resources that we're using just by completely misrepresenting the computational power of nature, and so for me, the technological answer to your question is essentially a do over of computer science. We had a good few decades, but it is an unfixed physical, it is a fiction and we need to make computation work in the same way nature does at all levels of description. We pretty much had to know how to do it.

>> William Press: We're running out of time. Peter, a quick pithy comment on that one?

>> Peter Schwartz: Just that I agree with Craig. I think the unique situation is that computer science is one of the only forms of science that's an entirely human invention, so there's no limit, no constraint. You know, the physical sciences, you know, things can only go so fast, use

so much energy. We can invent literally a science, and we are inventing it in computer science. The upside potential in terms of investment, no doubt the most important tool of science in the last 50 years that changed everything was the computer. So it seems to me that the still great potential that comes from that is still yet to be achieved. I think Craig is absolutely right.

>> William Press: Susan, you get the last question.

>> Susan Graham: We have time for it? So I wanted to ask you Peter, you presented an idea of human systems in which in effect one would have more of a scientific basis for a lot of areas of social science because of the new tools we have to do that, and to your list of psychology, sociology, and so on, I would add learning. And understand a lot more about how people learn. And you also asserted that we're going to understand more about the brain and the mind. One of the things that we know is that different people have different capabilities, and they have different physical capabilities and they have different mental capabilities, and in the case of physical for example, motor capabilities. In the case of motor capabilities, we've developed a lot of assistive technologies to help people who are less able. Okay. So my question is, in the case of mental abilities, do you foresee that we're going to make progress in the same kind of helping people to improve their abilities, particularly given the assertions that both Neil and people in other conversations have made of the importance of having skills in order to live in the 21st century.

>> Peter Schwartz: Undoubtedly we will. We're going to do it both formally and informally. You can be sure there are a thousand experiments going on right now with how should we say, substances that might not be in the legal realm that are intended to improve things like memory, creativity, etcetera, and there is no doubt in my mind we will actually move into a world where it will be regular and legal. Look, parents already give their kids drugs to improve learning and memory, and so on, so we're going to move into the neural assist era, where we'll have electronic devices and chemicals that will improve cognition, memory, creativity, deal with people who have impaired mental abilities, and so on to improve their abilities. I think one of the big changes in fact is going to be not only smart machines, but a whole lot smarter people.

>> William Press: Wow. And that technology will allow future panelists to talk faster.

>>Peter Schwartz: Yes. Yeah. Thank you.

>> John Holdren: Let me add my thanks, I thought that was fabulous, I'm so glad you were able to join us, we really appreciate it. [Applause]

>> Eric Lander: Thank you guys, tremendously stimulating and enlightening. We are not going to be taking a break, we are going to immediately swap to the next panel. So if everyone can stay put, our next panel is coming in.

Proceedings of the National Academies of Sciences and STEM Education

>> John Holdren: So we are grateful indeed to our three panelists, Shirley Tilghman, Marc Kirschner, and Harold Varmus for joining us today to elaborate on some thoughts that they published in PNAS, and which have generated an interesting and important wider discussion in the community. Their bios are all in the material provided to the PCAST members I'm reluctant to take important time by reading parts of their bios, these are certainly three of the leading lights in the biomedicine community. Leaders in thoughtful assessment of policy, as well as in science and in management of institutions and enterprises. So welcome to all of you and I don't know, have you agreed an order among yourself?

>> Eric Lander: No, we figured they probably had a plan, we're just going to give it over to them.

>> John Holdren: Good.

>> Eric Lander: What is the plan?

>> Shirley Tilghman: The plan, we drew straws and I got the short one.

>> Eric Lander: Great.

>> Shirley Tilghman: I'm going to (inaudible) frame the discussion and of course we're going to open it up (inaudible) There. Okay. Do I have to repeat that?

>> John Holdren: We are live streaming this, they won't hear you if I don't have your mic on.

>> Shirley Tilghman: So Harold and Marc and I want to begin by thanking you for the invitation to come and speak. One of our goals in writing the paper was to catalyze the discussion as broadly as possible, certainly within the biomedical community, but more broadly and we can't imagine a group that we would rather be having this discussion with than PCAST. So John and Eric, thank you very much for inviting us. Having just sat down and reread your November 2012 report, on the state of the U.S. research enterprise, I suggest that much of what I'm going to say is going to feel a little bit like preaching to the choir. As I read that report and read some of the recommendations that you had in that report, although you were speaking on a much broader scientific campus than the one we've been talking about, many of the things that we wrote about are actually embedded in your report. So I feel as though we're talking to our people here. I assume many, if not all of you, have read our paper. I don't want to go over it, but I do want to frame the discussion, we're going to have I think one of the wonderful things that Marc did when we were in the middle of our deliberations was to write down what he believed was a series of principles that would guide someone who was trying to create a research enterprise that was fertile as possible and that would produce the very, very best science. And it was in the I think for Marc, it was a wonderful exercise, for those who benefits from it, it was really illuminating, but one of the things Marc realized is that those principles had actually been laid down almost 70 years ago. And although many of us who think about science policy in the United States go back to Vannevar Bush over and over again, I find it is one of the most inspirational thing to go back and read that remarkable report, Science, The Endless Frontier because he pretty much captured the principles Marc laid out in 2014 and he did it in 1945. What are some of the principles?

>>Marc Kirschner: Story of my life. [Laughter]

>> Shirley Tilghman: You know, I think what comes through the report over and over and over again is fundamental importance of basic science. He called it the scientific capital, I call it the seed, corn, that drives the entire enterprise, but he reinforces this over and over again and I think in 2014 that is a message that probably needs reinforcing even more than it did in 1945 when we live such short horizons, such short term expectations and quarter to quarter thinking. So the importance of basic research, why it is essential to the entire enterprise. He said there needed to be research ecosystem and the role of the Federal government, although broad, was first and foremost to supply the resources so that basic research could be done because he didn't see that there was anyone else who was going to do it. I think that has proved absolutely the case. His belief that it should be done in conjunction with education, so that the main beneficiaries going to be research universities, research institutes that trained students and fellows, but he said something very interesting, I think is relevant to our paper and relevant to the conversation we're going to have. He said it this way. The government should provide reasonable number of undergraduate scholarships and graduate fellowships in order to develop scientific talent in American youth. The plan should be designed to attract into science only that proportion of the youthful talent appropriate to the needs of science in relation to the other needs of the nation's high priority. And I think that is one of the places where we have in biomedical science gone astray. We have forgotten that we are training students to provide to the needs of science in the United States and increasingly frankly all over the world, which is very important. He believed that in order to do fundamental science, basic science, innovative, novel science, scientists needed time, they needed the benefit of long horizons and they needed some sense of security so that they could think long term and we worry a lot that that is also being undermined. He has wonderful quotes and I'm not going to give you all of them, but the supreme importance of affording the prepared mind complete freedom for the exercise of initiative is one of my favorites. Understanding that someone who is going to be creative and inventive needs time to do so. He believed it's all about the talent. All of us no matter what kind of an organization were in or an organization we run believe that it is critical that we attract the best and the brightest. Sputnik helped do that in my generation. Helped inspire my generation to think about careers in science. We worry a lot that what is happen nothing biomedical science is no longer attracting the best and the brightest and if it's really all about the talent, which I firmly believe, we're in trouble. And finally, and I eluded to this already, the importance of stability of funding. So as I read the report, it just seeks remarkable to me how pressing it was and how relevant it is to today. What are the things we're worry body and wrote about the in the paper? Number one, the lack of predictability of funding. The NIH budget, one of the figures that I sent around is a figure that I originally got from Elias Zerhouni, former Director of the NIH, it shows the percent increase and decrease of the NIH budget over time looks like a saw tooth, looks like shark's teeth. This makes it extraordinarily difficult to take the long view and have long horizons which is what you need to do the very best funding and this is an issue

we hope to discuss in some detail with you because we noted this is an issue that you paid a lot of attention to in your 2012 report. What we call the Malthusian dilemma. I don't think that there is any question, certainly not in my mind and I don't think in the mind of my co authors much of the lacunae we describe in the paper, the root of that can be traced back to the fact if I want to put it in the most simple terms, that right now we have far too many people tracing far too little money and there are, you know, two ways of potentially fixing that formula, one is to increase the budget and it would have to be increased very significantly. But importantly would have to be increased significantly forever. For all time. And the realistic expectation that's going to be true certainly in the horizon that I think most of us are thinking about five to 10 years, seems unrealistic so we're going to have to really think about a system where there is frankly in my over population. So the Malthusian dilemma is creating longer training paths, the reason people are 37 before they get their first job and 42 before they get their first NIH grant, which is really what you need to get your lab up and running, is a direct result of this Malthusian dilemma. I worry about the impact of attracting the best and brightest, see it from the perspective of Princeton University, where I have conversations all the time with some of the brightest and the best young people in this country who are really skeptical that there is a fair opportunity for them to be a biomedical scientist and I will recall for Eric a conversation that he and I had in 1998, when this problem was being described, not for the first and not for the last time, Eric stood up in front of the audience of fellows and students at the White House and said, if I have looked that the at the age of 22, I would not have thought for a moment about going into a career in biomedical science and my guess is Eric's still believes that today. I think there are really quite significant negative consequences for senior investigators, as well as junior investigators, I tend to focus my concerns in the past on junior investigators because I really do think they are the future and I hear you just heard from futurist, so we know they have great ideas for what can be done in the future. But senior scientists and all of us have been in conversation with fairly broad swath of scientific community over the last year or so, our feeling the impact of the too many people chasing too few dollars and the most serious is the loss of that time to think. The loss of that time to really engage in the kind of deep thinking that needs to be done to do the very, very best science. And finally, the final impact of the Malthusian dilemma we worry about a lot is the risk aversion that we can detect among our colleagues in the way they think about planning their experiments and the way in which they think about writing their grants and the way in which they think about launching new research ideas. There is sort of a paw right now being cast in the scientific community that is leading to the very thing that will kill great science, which is the unwillingness to take risks. And if we don't care about any of the things that are happening to the individuals in the system, the thing we absolutely must care about is that we have a culture that encourages innovation and I worry that we're diminishing that culture. So in writing the paper, I think it really began with a conversation that Marc and I had at Harvard about, about two years ago now, we recruited

Bruce and Harold, old friends, thoughtful leaders in the scientific community, and it led to the publication of the paper, but we don't for a second presume that we know what to do now. We made recommendations in the paper simply as way to catalyze discussion and I'm going to let Marc or Harold tell you sort of what has happened since the paper has been published and how we're thinking about moving this dialogue forward.

>> Harold Varmus: Thank you. I'm going to summarize briefly some things that happened since the publication of this paper so you're up to date on where we are trying to pursue various initiatives, both trying to dissect the system, understand it better and to make recommendations and improvements. So I think all of us would probably agree that we've rarely had this much of a response to any scientific paper we ever wrote, more widely read, more widely commented on and with citation number, I hope impact factor is high, might help on my next grant, but no doubt that we've had generated tremendous amount of interest. We had thanks to Inder Verma and Ralph Cicerone, a meeting which occurred about a week after the paper was published and I don't think of my colleagues as early risers normally, but there were well over 100 people on Tuesday of the academy meeting which is when usually things are over and people have gone home, at 7:30 in the morning, I'd like to think they want to discussion the issue, not eat bagels that were provided. There was very heated discussion then and we realized we needed to have a more disciplined discussion, one where all the issues were laid out, not just peer review, the major focus of that academy discussion. So we organized small meeting that was in facilities provided by the Howard Hughes Medical Institute to allow us to bring together some Presidents of universities, many scientist leaders, whose names you would recognize, some economists and sociologists who may attention to these issues and number of others, 30 or 35 in all, to discuss the major things that Shirley has talked about, how we review each other, how money allocated, how universities and government are fulfilling their side of the contract. And the meeting was intended to be preparatory much larger meeting than we talked about as possible simulation of the sill mar meeting that occurred in the mid '70s that ended up governing members very well and we thought what would happen everybody would agree on the state of duress in our community that they would all feel we had laid out the next steps pretty well and that we would then convene this meeting and been how to organize the big meeting. The meeting itself proved somewhat different. That is everybody agreed that things were in disarray and the pursuit of biomedical science and the optimal conditions that Shirley has described and Vannevar Bush described in the years earlier. There was recognition some things needed to be done, but very deep concern that there wasn't agreement of any sort about how to do, what to do. And the feeling that was if we tried to assemble this large meeting and all went to the mount, that we would be unable to come off the mountain with anything that resembled the 10 commandments, probably empty tablets.

The feeling was we should continue the discussion, let me tell you how we planned to do that. It was agreement that we had gotten into this parlor state over many years, the system has actually performed pretty well. We remain leaders in biomedical research throughout the world and we shouldn't should do not harm and spend more time gathering views and the graduates new ideas, so we came up with a list of things that we intend to try to catalyze over the next several months. These items description of the meeting will soon be published somewhere, the text is here, the publication has not yet occurred, but the writing of this, summary of the workshop will be number one and dissemination, we are going to be creating a group that is larger than the four of us, because clearly we need a more diverse for lack of better word, group of people, young and old and various disciplines to think about how this ought to be, ought to be engaging on various fronts, with people who could help rectify the situation, develop more workshops. We know many trainees on the East Coast and West Coast some in the middle have been organizing full day discussions of some of the issues because I think younger generation has been astutely about the problems long before we became semi articulate about them and much of what I hear from younger people is just a sense of gratitude that people who are comfortable in the field like us are paying attention to it. We're developing a website, not yet ready to provide the URL, that will be a way to promulgate ideas and from wide range of people. We are asking leaders and institutions where in accord with Vannevar Bush principles, things happen, training programs develop, or the evaluation system is embedded where lab size and the growth of science actually occurs, to think through the issues and plan with us. And there was recurring theme at our workshop at the Hughes Institute there, isn't enough good data and not enough good modeling about how various changes here in funding or in training or in organization of labs would affect the enterprise. Very difficult to do that kind of strategic planning because we don't have data about what's happened in the past and because our science does work in a very desegregated way, the right thing, it is hard not dealing with a simple machine, we're dealing with collection of operations and many different kinds of institutions run by different people. It's hard to think about what the impact of changing support of graduate training, for example, would be like. And then we also continue to think about reached time when larger meeting try to resolve the intent to act on some of these proposals we put forward would be right. Of particular interest to us is the is getting whatever levers organizations like NIH have to govern training and growth of institutions, should be pulled and to think about whether we can persuade Congress at some point to think about rolling five projection of where funding ought to be without trying to fight the battle to get multi-year funding, which I think is a very dangerous battle anyway. Say one more thing in response to what Shirley has to say. Obviously I agree with all the things, I would like to clarify one point from my own perspective about the question of what it means to train the scientific workforce in accord with the Bushian principles of satisfying the nation's need for scientists. I think that proposition has changed somewhat. No longer thinking about people training people to do laboratory science, we're thinking about the way in which science utilized in this country in a wide variety of areas and I think it's quite clear to most people that the training that's been done in the biomedical research enterprise at least has been very targeted to the recreation of ourselves and what was known five or 10 years ago as alternative career using science to teach or to write for a magazine or to bring to bear on legal issues or business and financial services is no longer considered alternative career because of the people entering graduate train nothing our fields right now. Not every segment of our enterprise, but most segments, only roughly one in 10 likely to end up in an academic position. So we just think about how we structure train nothing a way that still encourages the very smartest peep toll come in and gives options along the way. Take a masters and do something else, finish a PhD and go into some other field or work for industry or take on a job as a staff scientist rather than independently funded investigator, even without PhD training. Post doctoral training. I think the flexibility of a system that we move towards with different kinds of ambitions will be quite importantly, let me stop there.

>> Marc Kirschner: The other few things actually two presentations and three people from the beginning, I get a chance maybe to say a few words and comment on one side. I think first of all, we have a very adaptive system, system is adaptive and that's, you know, changing with the pressures and the opportunities of changing the lifestyle, changing aspirations, changing what they work on. Generally we think of adaptation being a good thing, now adaptation, as well, what is happening in our system is a mixture of very good adaptation and very bad maladaptations. Part of it is stress in the system that's who root cause is what Shirley has described, but the effects of the stress, I mean more serious than just having a lot of disappointed people out there. I spoke last week, invited to speak at the Center of Scientific research NIH, which runs the review panels there, and they, I mean there is a lot of interest in what I said and there was a long discussion afterward by NIH, but the one thing that was really clear is that they, most people there felt that they couldn't do their job well when the pay line, when 1 out of 10 grants is really being approved. One out of every three grants, the system which is never perfect anyways and everybody knows it, could at least capture the signs. One out of 10 grants, you might have thought enrichment for the very best science, but it doesn't work out that way. It turns out to be the most risk adverse science, it turns out to be what people imagine the way the winds are blowing instead of consulting their own heart, what they want to do. So that's just a measure of this stress in the system. And the point I really want to add here, it's not just a stress on the people, but it's a stress which is affecting the science that is being done, the kind of people entering the system and ultimately productivity of American science and therefore it is very, very important for us to consider even if we were not to be concerned with the human waste that might be going on in the system. In general, as I look

back over the history of science, I don't see stress as being a particularly helpful thing for good science. Darwin didn't have to work a day in his life and he had people taking care of him all the time, worked very, very hard. I don't think you could say he was an unproductive scientist in the 19th century, many scientists, most scientists were wealthy men who had everything laid out for them, but they were still quite productive N. Our century and more Democratic society, we it is not just a wealth, but we try to ensure that people have the opportunity to follow their own imagination and the reality of science today for biomedical science and maybe in other sciences, as well, is that people are spending too much of their time writing grants, rewriting grants, a plying for grants, writing papers, rewriting papers, satisfying very competitive system, own pathology, dealing a lot of administrative burden and far too little time, I know it sounds kind of quaint to talk about these things, but I think there is a real cost here. Too little time to think on their own, too little time to consult, other scientists to their colleagues, to read and very hyper competitive environment which is created now by stress of unfunding, things have gotten much worse. It is very hard to measure that, but the anecdotal reports from every single person we've talked to and every part of this field support this. I think we can't, you know, I wish there was a quantitative essay I could show the effects of this, but I think it is undeniable it is happening. So I just want to point out this is not just about manpower workforce problem, but it's a problem about the effects on the very science that we're doing and the future of the scientific community. Finally, one last thing, having gone from a culture of aristocratic science to more democratic population in the 20th century, there is a desire to open this up to even broader range of people who are not so well incorporated into the community. And the stresses that we're talking about I think are particularly damaging in any hopes, particularly of women in science, this is becoming one of the real barriers for that. But also other people, as well. So that's an issue I think that of kind of waste that we're also going to have to deal with.

>> Harold Varmus: I think I've neglected to mention that (inaudible) was at the workshop as well and she might want to comment on how it was perceived from the OSTP point of view.

>> Eric Lander: Okay, I've got a whole list of names.

>> Harold Varmus: You going to share Eric? I love the quaint erection of your name cards.

>> Eric Lander: As from when you were one of the Co-chairs, we have maintained our pattern to signal our interest by turning our flags vertically. And I actually turn mine vertically first, I'm going to start us off and I have a whole list of people. I want to start off by

>> Harold Varmus: Chairman's Privilege.

>> Eric Lander: Well actually, Chairman put his flag up first, no active privilege.

>> Eric Lander: I intend to call on Jo at some point, I first want to thank our colleagues here for having just created tremendous productive discussion in the scientific community around these issues. This really did get everybody's attention, everybody, you know, where I hang out around MIT and Harvard have talked about where we go, people have been paying attention to the article. I do want to pick up on some of the threads that you have mentioned already, which is you have acknowledged that you have identified that there's a stress and you've hypothesized and suggested possible cures and that's exactly what is needed in article like this. I'm really pleased you step back and say, okay, now we have to turn the hypotheses into testable hypotheses because the explanations you give here over determine the situation, maybe some of these aren't the most important explanations. I hear in this whole mix, things like stress is caused by low pay lines, that feels right to me. Is that cause considered too many people in there and do you want to shut that down by turning down graduate student? Do you want to shut that down by decreasing the reimbursement to universities to not create and hospitals to not create positions that will get reimbursed through overhead and building or maybe that not the problem at all and it's that young people are really frustrated when they submit a grant and find out a year later it's not going to be funded because of stupid reasons a simple conversation could have gotten past and a system in which two months you could get a signal for something with application, you'd get a signal and it was fair, maybe that would create a situation where some people said, I'm not going to succeed in this business, I'm going to get out and the best people would stay in. I don't know whether it's the number of people and whether people falling away is the problem or whether it's the best people are falling away because they're frustrated by a very frustrating system where they can't get straightforward answers pretty darn quickly and think they are going to do multiple grant cycles. I'm glad you raised people reviewing when we get into a situation where that seems competition there. Not only do I want you to support the paper you wish to write, I wish you to write the paper I'd like to write by including 10 other things of interest to me, but not to the author is a standard thing in biomedicine and administrative burden. This is a great brew of ideas. How to turn this into testable hypotheses and then how to make sure we don't get perverse unintended consequences because of everything I just named here, the number of students here, cut the university reimbursement or that, limit grant size, for every one of those, you can think about

reverse consequences that could happen and a full discussion of this should really enumerate all the ways in which this prescription could actually be worse than the disease. I think you all said that, I'm just trying to draw that all out. I'm enthusiastic that you are pushing us toward a serious and rigorous conversation about all these important issues. I don't know if you want to, that is not a question, I'm agreeing and elaborating. You may want to respond.

>> Shirley Tilghman: The one response that I would offer is that at breakfast in the morning I said, "if I were a member of PCAST, here is the question I would be asking us", and it was your question, which is which shows how long I've known you.

>> Eric Lander: Exactly. Neither of us will actually say how long that is.

>> Shirley Tilghman: You know, Jo may want to weigh in on this, as well. One thing we learned at the HHMI meeting is that there is I think with maybe one exception, consensus about the diagnosis, that the system is under extreme stress and is at risk of becoming less inventive and creative than it needs to be deserve nations in the world to me. There was very little consensus about what we should be doing about it and that's why we decided quite quickly that we didn't have the grounds for a large meeting and Similar like meeting. To go into a meeting, have you to know where you want to come out of one of those meetings. I think we are beginning to think about the kinds of conversations that we need to catalyze within the scientific community, has to be much broader conversation than the ones four of us having with each other or that we had at HHMI with very, very senior respected leaders in the field. The voices that are missing so far, the young voices and we need to get them into the mix. We're tremendously sensitive to the first do no harm. You know, this is an enterprise that has produced tremendous good for mankind and the last thing we want to do is meddle with it in such a way we destroy what has been so good. So we're open to your thoughts also about how we could proceed to keep this conversation going. I think the one thing we know for sure is that if we just all go home it's going to get worse. And that would be a tragedy, truly be a tragedy. We need to figure out all the ways in which we'll open this conversation up. The last thing I would say and then I can see Harold has his finger on the button.

>> Harold Varmus: I don't know if we, as speakers, need to raise our name tags.

>> Eric Lander: No you do not, but you are welcome too, if you wish to, Harold.

>> Shirley Tilghman: That I well, now I forgot what I was going to say, you go.

>> Harold Varmus: I just want to make one point about the workshop which ties in nicely with something that Eric said. There was probably more attention paid to one single observation than anything else at the workshop and that is the change in the number of investigators in the NIH system and people supported by NIH money under the age of 36. So little over 30 years ago, that was 18% of grantees and a few thousand people. Now it's a few hundred and it's 3% of the total. Now that's a number which, you know, it raises eye brows and hackles. It's not entirely clear exactly why that's happened, citing facts at breakfast this morning about this is just due to longer post doctoral training, the fact universities provide start up packages, is it due to the fact that peer review groups are requiring more preliminary data so people don't apply for grants, the fact people feel they can work more effectively as post doc, especially in a lab like mine, you get credit for pursuing your own dreams as post doc, and once you become faculty member, you have to deal with the burdens of administrative compliance and add on teaching and grant writing and being the person responsible for answering 18 reviewers on paper and nature cell to make extra ordinary demands. So just hard to know what the right hypothesis is to explain the changes and then the question is how much does that matter? Seems to me it matters a lot because most of us who think back to the early days of scientific careers say we did our best work when we were in our 30s. Yet maybe, you know, something is the new 36, and life is different; right. I think all those things are potential substrates for creating hypotheses.

>> Eric Lander: I'm going to suggest Maxine, Jim Gates, I'd like to get Jo's voice in there, if that is okay. I know I have a bunch of other members, move quickly.

>> Maxine Savitz: I'm moving the other end of the pipeline, in industry. There is little mention of industry in here and you Harold, mentioned replicate ourselves, one other area, in the engineering chemical field, we don't have, now have post doc engineering, which they didn't before. People work with industry early on and even in graduate, undergraduate, what are where is the pharma industry, the device industry, how do they weigh in to what you are doing and where is looking to the future? There have been a lot of start ups.

>> Harold Varmus: Good point about our paper written from academic perspective, we mention the fact there are jobs in industry and that is one of the ways in which many trainees move forward in their careers. The kinds of optimal jobs starting level that are found in the pharmaceutical industry in decline that, is due to biotech, as well, there is still opportunity for employment there and many people do end up there and certainly is one thing that should be more clearly considered during the training process. We haven't had a lot of feedback in my experience from the industries yet, but should be getting more of that. We do recognize that what we've had to say does not apply to all fields and doesn't apply to biomedicine, bioengineering is a field underrepresentation, very good people and less competitive. Ditto for bioinformatics and computational sciences and the chemistry issue is also very important one because chemistry remains important in biomedicine and we know that there is shortages in pharmacology, pharmacokinetics and so on, I think it is very complex landscape and one reason we're nervous about moving forward too fast on some of the things is because we don't want to do damage in fields that don't conform to things we've said.

>> Eric Lander: Let Jim jump in. Jim, Jo, and them I'm going to ask PCAST to gang up a bunch of questions to let the panel as we have done sometimes before, Shirley, did you want to say more about that?

>> Shirley Tilghman: No, I was going to point out one figure that we provided for you in advance shows what has happened to the likelihood of being employed six years after PhD in various sectors of the economy and what you'll see is that the percentage that goes into the private sector has stayed pretty constant since 1993 and what's happened is the percentage that are going into academia, particularly into tender track has gone down very significantly and the only category that's gone up to compensate for that is are PhDs who are no longer working in research relevant jobs. That's the landscape.

>> Eric Lander: Jim.

>> James Gates: Thank you, Eric, and thank you, panel, for the wonderful brief. Good to see some of you for the first time in a while. I as I meet people, I get carry ghosts around from various people I meet. One colleague who shouldn't here today is Chad Mirkin and Chad has

persistently throughout...he is for me. But one thing he persistently brings up is brittleness that one can see in losing researchers on the global platform. That is we're so used to being in preeminent position in this country, you are starting to see at least in nano technology, the threat that some of our best talent is now starting to out migrate and perhaps begin to find have other systems that become beneficiary of that talent, talent you are talking about. You can point to that sort of thing going on in your discipline also?

>> Marc Kirschner: Probably not so much, but I mean, two reasons why that would happen. One is I would be happy about, and that would be if other countries really did some wonderful things in this area and I think for so long, people come to this country to work, wouldn't be so terrible if they went to other countries and did things. Certainly a huge investment now in China and that is I mean such that the packages for young faculty in China in many cases better than the packages in the United States. But there still is a place where most people want to be, I think. And I think partly it's because if we take Europe as an example, they also have not been heavily invested, I mean investment hasn't gone out as much as it should. But I want to say one thing about the about that. That is that the appeal to science in America probably was like the appeal of the United States itself as a young country with lots of opportunity, a place for young people can, you know, can do follow their dreams and be recognized while they're young enough to get the resources they need to do things. You know, I wouldn't say it isn't that way completely, but I think it is less that way and we have this problem of trying to maintain or in a state situation, the kind of spirit that Bush was trying to create after the war. I mean, he was talking about we you know, we need to turn science away from bombs to health or other things and he was very excite body it and we need to kind of boost the growth of the scientific community and need to invest in the university, need to get the military out of the universities, that is big point of what he said, kind of very negative about what the military contributed scientifically during the war, very positive about what fundamental research contributed during the war. And so he came from, after all, an engineering perspective, he was engineering at MIT. Foundation, he was coming from that community, but he was really saying that yet we had to create something new, something special here and helped create that. We have since more difficult problem of how maintain that sense of creativity and opportunity at a time when we're not in exponential growth. I think that we can, we see pieces of it happening, you know, lots of ideas, but I will say one thing in regard to what Eric said, I mean this, is the most when I think about making recommendations, unintended consequences and it's because everybody is jockeying for some way to continue and depends and is more imaginative than we are in terms of what happened. We saw that in a small way in the NIH change in the review criteria and grants and so which very thoughtful people, some of them close friends. Like they were doing some good there and most of them I spoke to now think in the end it was worse than it was

before. So it is a problem. But that doesn't, it is also another problem in that regard. Even small changes that we make probably are the right thing to do, may not actually have enough impact on the problems we have. It is not just a question of whether they are right or wrong, but how influential they are in changing the whole this is tough business.

>> Eric Lander: It is, it is good you have us squarely focused on it. I will ask Jo Handelsman if she might jump in, because she's an acute observer of these issues.

>> Jo Handelsman: Thanks, thanks for coming and thanks for holding our terrific meeting at HHMI, I think the whole process has been enlightening and provocative. I want to stress two points that I think you've touched on, but maybe need a little more attention that came out of the meeting. One was eluding to what Marc was just saying, we need different levels and types of fixes that, we need maybe short term ways to jump into the system and encourage people and I think what you're saying, Harold is the reactions of young people to the article itself and then to the fact that all people actually care about this issue has been really quite remarkable, which tells us a lot about what we could do to be encouraging our youth. Then obviously long term and bigger global fixes, some small fixes might be really important, even if they are small. Even if they only affect one tiny bit of the system, but I agree overall, we should be doing no harm. I think we need experiments and NIH has begun to do a few of those that I think should be very informative about the types of grants, the types of supplements for grants, the types of training that we offer. Then the other strain that came through for me and that I think is the most meaningful for me in this whole discussion is that I think graduate education is the pinnacle of education in this country. I think we do it extra ordinarily well and I think most other countries would like to do it as well as we do and I don't think there is anything wrong with unleashing very large fleet of PhDs and biomedical sciences on the world that are trained, as well as ours are. The question is what they then do and setting expectations that they will have the careers that they in fact expect to. And so I think we need to focus less on not training as many graduate students to train them more broadly for the careers they will actually have, changing criteria for evaluating things like training grants that currently evaluate very strongly on whether your graduate students end up in faculty position, therefore making alternative career the failures. And really looking at what we need to do to rigorously, as rigorously train people for other parts of biomedical careers or other careers, many don't stay in biomedical sciences, just as we do in research and train them in teaching as rigorously, train them in entrepreneurship rigorously as enterprise. Those are the two big takeaways I would add.

>> Harold Varmus: One brief response, I really appreciate your comments about graduate training, I mean, total agreement with what you said, but I do particularly am grateful for your comment about the minor things we can do. I think they are symbolic of larger things and represent experiments. Just to be explicit that in some sense, I am here as a private citizen in the biomedical community, I also do represent the NIH at one level and point out that NIH has taken on some changes in the way we evaluate people by changing the biosketch, it is not just about whether you publish and sell, what you did, five most important contributions will be the norm for biosketch to help evaluate the person. Secondly, the leadership at NIH from Frances Cordova has brought in the idea stable funding to people based on accomplishments and the cancer institute is the first out of the gate with new outstanding investigator award that provides seven years of support, quite a high level for our best investigators and quite significant numbers and that kind of program is being emulated by several other institutes. And one of the things that people complain about is the composition of the study section review grant, not enough senior experienced people and soon to be announced will be a component of the notice of grant award to include the statement that as a grantee of the NIH, you're expected to serve on the section if asked, so moving to a jury model rather than a draft model, people having traditionally said, I did my service as a 30 year old or 35 year old and now I don't have to do it anymore.

>> Eric Lander: Those are hardly small things. We have three remaining flags up. I might just ask that we go through the flags in order. I'm going to ask Craig and then Rosina and then Dan and give our panel a chance to both respond and make last...oh, Susan's flag was directly behind Dan. My apology, I did not see the flag there. We have four remaining comments and Craig and Rosina, Dan and Susan and then we shall thank you, you're just in perfect line there.

>> Craig Mundie: I think there is an interesting intersection between Shirley's comments about the risk aversion issue and to some extent, the peer review process and this long evolution to Democratic allocation model. You know, if you go back before that, was pointed out, the aristocrats funded this and essentially it wasn't a democratic process, you had their own money or had sponsors who basically believed in the person and the person got to do the work. To me this, is an important thing to consider, in particularly I would encourage to look at what happens in the business environment and why it is sort of a strong distinction between entrepreneurialism, you know, which is highly rewarded and has essentially evolved separate structure for all intents and services of venture capital. Sustaining support of engineering and business. And real issue is twofold. One is huge and valuable part of what people contribute is incremental. But the things fundamentally change the path are non-incremental. Dislocating,

discontinuous. In business we had books written like Christianson, the innovator dilemma, which document what is happens when you basically end up in a process that almost exclusively favors incrementalism. Physicists tend in that direction and I contend that you're just essentially finding out what business has known for a long time, which is that if you don't actually clearly distinguish, not just the funding mechanism, but the way that you identify the people who are entrepreneurial intrinsically, as opposed to those that are not, that you will never resolve this problem. And so I talk a lot about the peer review process, cannot be the only way you allocate funds there has to be some place, you know, where funding is done that is, you know, and not based on track record, great to say seven years for the people who quote already did it. All right. The problem is the venture capital equivalent in the entire scientific process, all right. And I think it's just completely absent. And so I would encourage you to think a lot more strongly about lessons you can learn from what's happened in the commercial sector because they frankly been running this movie a lot longer than you have since Bush.

>> Rosina Bierbaum: I commend you for this paper and my comments are more along the lines of Jo's in training the next generation, which you talk about in the paper quite a bit. You are talking about biomedical researchers, but these issues are coming up in other fields, PCAST had a briefing by the American chemical society last year where they said, we might be overproducing PhDs and we might be producing PhDs who are not really equipped to be chemists in the next generation because they are on research grants and advisory frantically fulfilling research grant and writing the next one for smaller and smaller amounts of money. In the report we did for R&D for energy we commented training grants as have you mentioned in your paper might be important and so I think that's emerging in that field, as well. In the paper, you do mention multi disciplinary training and renewed NIH master's program and statistics that we have at Michigan show about a third of master's students are doing interdisciplinary stuff two degrees in three years, marrying very different disciplines and public policy environments and given that the next generation is likely to have three to six jobs unlike us, enabling them to walk across the fields and actually training them to have credentials in more than one field especially at master's level I think have very important and then the last comment is that we do have independent confirmation that the external world is interested in these multiply trained folks and I just learn third degree morning triple an s fellows are 20 times the size they were when I was in one of the early classes, but there is a real eagerness both on the side of the scientist coming into the work force and in the various job opportunities to have some scientific expertise, I think all THF suggests that really to be problem solvers, we need to be training interdisciplinary students to understand both the language of science, as well as policy and economics, I think that argues that our mode of educating and our mode of evaluating appropriate expertise is for the next generation of scientists have to evolve.

>> Eric Lander: Great. Dan Schrag?

>> Shirley Tilghman: Can I just make one comment.

>> Eric Lander: Jump in.

>> Shirley Tilghman: That relates back to what Craig said, as well. We can think about all kinds of ways of innovating graduate education and actually the NIH is just created a grant mechanism called the best grant, which is designed to stimulate innovation in the way in which graduate programs are produced. But it is going to come back to the current structure of the research laboratory in biomedical science is graduate students are the worker bees that get the work done. And all innovation that you might want to introduce into graduate education will have to contend with the fact that their advisors will not want them off doing a three month internship at Microsoft or going to liberal arts college and teaching for a semester. They want those students in the lab producing research and that's why one thing we will have to contend with is the structure of the laboratory. How it is structured and of course that is something that can't change instantly. It will have to change over a period of time. But the problem with all of those good ideas that you just proposed, which I completely support, are incompatible with the current structure of our work force for producing research in academia.

>> Eric Lander: Marc.

>> Marc Kirschner: Wanted to jump in on something, first I want to underscore what Shirley just said about essentially all our workers in this enterprise are trainees. There's a set of tension in those two things. We want these people to be exploring new areas and the people also I are doing all the work, it's natural conflict. But at the risk of indirectly reflecting favorably on Eric, which is I always try to do it is a risk. The one thing which I think is important and comes from what Craig mentioned is the role of communities in fostering innovative science and supporting people who are doing long term things who are people who we find are brilliant and valuable, but haven't published a lot. So this is kind of in a way buffering against this very external where did you publish last review. And I think we've seen in biomedical science, many historic

communities, not so long ago, but in the Pasteur Institute and one time, Laboratory of Molecular Biology at UCF that Harold and I remember when we were there, but places, The Broad Institute is a very new example. Where there were some resources to make local decisions. These kinds of things are hard to do nationally and those resources are have gradually seeped away and in fact, it even seems unfair, why should the government be providing you indirectly those resources, but I think it's proven to be very important and cull indicates not only good science, but certainly kind of ethics of science, values in science, people in science, they are not always the people who publish the most paper make the biggest contribution to science. Some people open up feelings other people come in and exploit later on. And I think as we are getting closer to the edge here of funding and less money floating around, it's harder to do that. When I was a student, I started at Rockefeller and a person I ran in to was a chemist who hadn't published a paper in 10 years. We worked on, you know who he is, solid phase peptide synthesis and he got the Nobel Prize for it. That institution, that face in this approach, and supported for 10 years. So this is another, you know, aspect of I think it speaks directly to what you were talking about, that you have to have the resources to invest in it. Our present system doesn't allow for that very much.

>> Eric Lander: We will take one more question or so. Daniel Schrag. My colleague is noting the time is upon us because we're supposed to end at noon. Lowered their flags, but we can get another question or so, Dan?

>> Daniel Schrag: Thanks to everybody, I'll dispense with the formalities because of time. I think I'm really sympathetic to what Jo was saying about broadening graduate education and preserving the gem of our system. By the way, I run such an interdisciplinary program and we pay the students, Shirley, yes, you can't talk about broadening education unless you pay for it because that is exactly right in terms of time away from the grant. I still think it comes back to what you said, Shirley, in the beginning about the population problem. Even if we found broader things for graduate students to do afterwards, that only temporary fix just increases the pool more, we still have the same problem, which is that we don't have birth control in this country in terms of scientists. We talked about this a lot when Bill and Maxine led the report on the enterprise and I looked at the numbers from NSF, I didn't look at NIH, but at NSF, no question the numbers went up as application for grants came up, what happened program managers tried to make people happy by decreasing grant size or not letting them grow with inflation and that has become a killer in my field, earth sciences, where grants are not worth applying for anymore, they are so small. Average grant size in earth science at NSF are like $70,000 a year, with overhead, that includes indirect cost. Ridiculous.

>> Eric Lander: Wow.

>> Daniel Schrag: So it is really dysfunctional. Now you look at different models there, is Chinese model of birth control, I think have you to have that conversation, you know, call it one graduate student policy. But

>> Eric Lander: One graduate student per career.

>> Daniel Schrag: But in all seriousness, one of the problems that we have to talk about is the burgeoning size of the large laboratories in certain fields and that is question of you know it offends our sensibility of the best and brightest should be able to compete and get more grants and more grants and more grants and have a group of 50 people. Is that how we want to run our enterprise? That is the question. The second model would be British model elitist model, where you assign certain number of graduate slots based on ratings of top departments and department level that birth control model, that offends our American sensibility of open access and you know all of the rest of it. We have to have these conversations about that birth control, what we see is soft money institutions and in my field, Woods Hole Oceanographic Institute is cratering because of this problem where money is declined and suddenly all these soft money scientists who built up during the good years are now, I mean literally institutions are falling apart. I know Harvard Medical School is undergoing certain amount of no, I wouldn't say that, but they are going to reflection over the funding model.

>> Harold Varmus: But Dan, this is a place where the government university relationship really has to be worked on together and we heard a lot, I didn't mention at the Hughes workshop, about the increase in contribution universities making to the cost of research. And tinkering with indirect cost to get back to that is difficult and lab size is very significant extent depending on university practices, what they value, what they are willing to do, how they share graduate students, how space allocated and involving NIH for example could have some role in how big people can get. University has to be part of that discussion.

>> Eric Lander: Great. This is the beginning for us of a conversation about this and Shirley said at the beginning, we've been interested in this topic since the work we did that produced 2012 report. The report has really moved this conversation forward tremendously. I am sure we're planning continue to engage with you, but since the hour draws actually beyond the appointed hour, we're going to stop the conversation here, I want to thank this extraordinary panel, to get three out of the authors given how busy they are, to be here is quite a thing. Thank you very much for being here. [Applause]

>> Eric Lander: And for closing words I'll turn over to my Co-chair John.

>> John Holdren: Let me add my thanks to the panel, I thought this was seriously instructive, as well as thought provoking, both your opening remarks and the interactions with members of PCAST, terrific. I think the rest of our public session here has been at a very high level, as well, so I want to thank all of the participants and as always, members of PCAST are amazing staff, and all the folks on the wider community who join us in person and on the web. We look forward to seeing you all next time.