

## **President's Council of Advisors on Science and Technology (PCAST)**

**Public Meeting - May 15, 2015**

### **Transcription**

#### **Welcome from PCAST Co-Chairs:**

>> JOHN HOLDREN: If we can get people to take their places, it's 9:00 o'clock. And time for us to begin. It is a pleasure of me to open this meeting of the President's Council of Advisors on Science and Technology. As always, we have a full agenda. There is, as everybody in the room knows, a lot going on in this space ranging from the ongoing budget process in which the Congress is dealing with appropriations for FY16. We have a number of challenges in that space as you all know if you all read the newspapers or the blogs. And at the same time, we have a lot of exciting initiatives moving forward in the Administration, a number of which we will hear about in the course of the day. None is, I think, more interesting and exciting than the recent release of the Quadrennial Energy Review, which is a project that was originally envisioned in a PCAST report in the fall of 2010. Secretary of Energy, Ernest Moniz was at that time a member of PCAST and together with Maxine Savitz, one of our vice chairs, led the study, the PCAST study, that recommended a Quadrennial Energy Review, and as the Secretary of Energy, subsequently Ernie has played a major role in delivering on that promise. I will turn it over to my Co-Chair Eric Lander for his welcome and then we will proceed with the agenda.

>> ERIC LANDER: I want to welcome everyone who is watching on the web, everyone who is present here in the room, and to thank the members of the PCAST for their continued service. As John has said, we have a tremendously full agenda here at PCAST. And the sessions this morning are on no small topics, starting with the Quadrennial Review and moving to Precision Medicine, and moving to the fundamental questions on how the system can best deliver for the American people, so we have a lot to do this morning, so I want to thank everyone and turn back over to John.

#### **Quadrennial Energy Review:**

>>JOHN HOLDREN: Secretary Moniz is accompanied this morning by Jonathan Pershing the Principal Deputy Director of the Office of Energy Policies and Systems Analysis in the Department of Energy, an office that played a major role in the Quadrennial Energy Review.

And so welcome to Drs. Moniz and Pershing, and a pleasure to have you here this morning. The floor is yours.

>> SEC. ERNEST MONIZ: Thank you, John. It is indeed a pleasure to be here as you said, in particular it feels like coming back to the birth of the QER back in our report in late 2010. And let me -- how we'll proceed, if it's okay with the Chair is that I will give kind of a fairly broad overview of the QER. And both process and content, then I'll turn it over to Jonathan who may be showing some slides, as well, to give a little more color to a few of the recommendations. Let me say off the bat that the QER process has very, very closely followed the recommendations made by this group to the President and I think it has served this process quite well. First, the President announced the QER in his 2013 Climate Action Plan, including the first focused area on energy infrastructure, transmission storage and distribution of energy. That was codified by the President in January of 2014, and has led then to this roughly year and a half effort to produce as PCAST requested a heavily data driven and analytically based product on energy infrastructure. I might add that many of you presumably have read this entire document, but I want you to know that your pleasure will not be mounded by this as we still have appendices and independent analyses that will be posted shortly on the web, and we can come back and do it again. As John already mentioned, at DOE in terms of serving as the Administration Executive Secretariat, we established this office with Jonathan as principal deputy the Energy Policy and Systems Analysis Office, with now over 60 professionals and I must say, I think it is an extraordinarily strong analytical group, and certainly for carrying out the Government's business, I think they have done an exceptional job. I mentioned the process of following the original PCAST recommendation that included the fact that in some sense the convening power for the 22 Federal agencies that were engaged rests here in the Executive Office of the President. Well here I'm thinking of John, therefore, here, so John Holdren and Dan Utech from the Domestic Policy Council were the co-chairs of the effort. DOE then again served as kind of the home for the analytical effort but very importantly pulling in colleagues from across the Administration because as the PCAST report emphasized back in the late 2010, energy equities, energy interests are just distributed practically across the entire Administration. And that frankly does add complication. But in the end, we believe produces a document that has a lot more strength and will serve as the basis for continuing discussion across the Administration, and perhaps more importantly between the Administration and the Congress as we go forward. I'll return to that point at the end, well maybe just to make sure I don't forget I should add that it's clear from the public statements that have come out of the Energy Committees of both the Senate and the House, that there is an eagerness on the part of those committee leaderships to engage with the Administration on the basis of the Quadrennial Energy Review to try to move some bipartisan legislation forward on energy infrastructure as

the QER points out, we need it. So we are looking forward to that. And once again, by the way, in the meetings that we had in PCAST leading up to the report, we did speak with Members of Congress, and interestingly they said right then that this kind of integrated document was what they needed to have a discussion across the energy space. So this is one case where at least so far I think it's kind of working out as we had hoped. Finally, just to mention that in parallel, the second installment of the Quadrennial Technology Review, that was also not quite with that name but that same effort was also part of the PCAST report focused on the research and development needs across the energy space. That is well along. Again, it's a major analytical effort. It will provide, I think a lot of insight in terms of what is going on and what needs to go on across the board in energy technology, energy science and technology, and we are hoping that will be ready in June but it's another major effort. So let me again now just turn to saying a few things about the QER at a fairly high level, and then Jonathan will add, again, some more specifics. And then we will of course be happy to discuss. There are in some sense four large core areas addressed in the QER with its infrastructure focus. One is the need that as we look forward -- in fact I should say to start I guess I take it for granted, but we should emphasize that we have -- we are in a period over the last decade or so of quite remarkable changes in the energy system. Everything obviously from the production of hydrocarbons has been a tremendous economic boom, it is also as the QER points out, quite stressed much of our energy infrastructure. That's an example of something that has to be responded to. But on the opportunity side, we also know that we have seen tremendous technology developments, and again one of the obvious ones there is the precipitous drop in the costs of a number of clean technologies. On shore wind, solar, LEDs, batteries, just in a period of five to ten years, we have seen cost reductions in some cases by multiples. And this is very important, it also emphasizes looking at infrastructure investments which tend to be long term, we need to have a certain robustness to different energy outcomes, especially in different regions of the country. So that was one of the guiding principles. Now going back to the idea of having four major kind of thematic buckets, one is the whole issue of resilience. Resilience against the kinds of risks that we are seeing and will be seeing in the energy infrastructure. That includes clearly risks driving from extreme weather. Things like storm surges, as we all know for example, have had huge infrastructure impacts. To things like cyber risk. So there's a whole spectrum of risks. And we need resilience to these risks, some of the areas that we consider then and make recommendations are on for example, engaging and implementing things like large electric transform reserves we know these are potentially low probability but potentially fairly high consequence in terms of replacement needs, whether the shortage comes from natural or unnatural causes. We look at the situation with our country's natural gas infrastructure. The distribution infrastructure in particular one of the themes and it's good to highlight, as with much of our country's infrastructure, and the President of course and the Vice President have both emphasized the need to address this country's infrastructure more broadly if we now look

at the energy infrastructure, the estimated bill for modernizing our natural gas distribution infrastructure is roughly a quarter of a trillion dollars. And that has environmental implications, particularly methane emissions, and that's another theme the Administration has been focused on very much for the last year. But of course it also has safety implications. And in fact we have seen too often in the last years the consequences of not addressing the upgrading of that infrastructure. I will come back to issues among the resource requirements. But that is a second area. We do propose a relevantly small but important new state grant program for states to be able to update energy assurance planning that we hope would then be the basis for large project execution. Let me give you an example of what we have in mind there. This is not QER specific but predates it somewhat in the aftermath of Super Storm Sandy, we Department of Energy, cost shared with the state of New Jersey a study involving one of our national labs as to how a microgrid architecture with distributed generation could be employed to provide resilience of a critical electrified transportation corridor during emergencies, so again a public safety issue as well as an energy issue. That then relatively modest cost shared project, as might come out of an energy assurance planning at the state level, led to a successful application to the Department of Transportation for Sandy recovery money to hundreds of millions of dollars to implement this plan and I think that's the theme that as we build and rebuild our infrastructure, we have to build it smart, we have to build it resilient for the risks and opportunities of the future, and not just rebuild as we too often have just rebuild what we lost in a storm or some other situation. Secondly, another major bucket, modernizing the electric grid, of course resilience is part of that, but we have seen that the cost of weather-related power outages has gotten very significant. We're talking in the \$100 to \$200 billion range over a five-year period, so we are promoting grid modernization. This is a good example for me to talk about and what was clearly I.T. is one of the major themes in both the transmission and distribution sides of the infrastructure. The -- so this is a good example to talk about the resource requirements. So this is a case where we estimated a Federal funding requirement in the \$3 to \$4 billion range over the next ten years for grid modernization. A lot of technology development. Again, state grant programs, a variety of approaches. But in this case, we put \$350 million in fact into our FY16 request. So the message is, some of the elements of the QER are in the President's funding request currently before the Congress, while others I mentioned for example the gas distribution infrastructure, a quarter of a trillion dollars that clearly is not in the budget request for FY16. But there the idea is the following, so the way we managed in that case the resource requirement is to estimate how might there be a Federal program to assist in relieving rate increases among low income households to be able to accelerate replacement. Just as a personal anecdote, I at least currently have a little place here in DC. And Pepco, now in my monthly bill, it's got a little surcharge for modernizing the gas distribution infrastructure over a 40-year period. So our idea is well, maybe there could be a competitive program to shorten that to a mere maybe 20 years and that, however, would mean near term higher rate.

And so our look is to see a much more modest \$4 billion or so fund to help acceleration and relieve rate shock for low income households. Just to give you very different flavors in the QER which we believe are fit to task. A third big bucket area, shared infrastructure. By this I mean the infrastructures that move not just energy but many commodities like inland waterways, rail, docks, dock modernization, et cetera. There are already Administration proposals for various fee structures to help with some of these issues. In the QER, we proposed a very specific example called assets actions to support shared energy transport systems which in this case would be a \$2.5 billion project over ten years mobilize at least double that amount of private capital to improve the connectors between docks that are heavily involved in the energy sector to the inland transportation. This -- it's a huge problem. It's a huge problem economically. We have trucks lined up at these ports for hours and hours of waiting time. And, by the way, it's an environmental problem because of the emissions that that entails. And finally the -- well, no, I guess that's the oh, I'm sorry, energy security, I forgot one of the major buckets. So as an example modernizing the petroleum reserve is important for two reasons we identified. One is that there simply is physical modernization that is required in terms of caverns and the like. But also because of the stresses on the overall distribution system from the enormous increase in our oil production in particular, we have distribution problems with this and we need to especially improve the opportunities to get oil in an emergency onto water, so we propose about \$2 billion for upgrading the petroleum reserve. The last element I'll mention, which was also an important part of the PCAST report recommendations, was to include North American energy integration as an important subject. So in our outreach, and I should have said earlier, we had I think 14 meetings in various parts of the country. One of those meetings was actually in Ottawa. We already have a very, very high degree of energy integration with Canada. But the opportunities now may be even greater -- I mean opportunities for new integration with Mexico, Mexico's energy reform is both in the hydrocarbon and in the power sectors, and this will open up many possibilities for cross border integration, including of the electricity sector and we have working groups between the two countries to explore this. We also have trilateral working groups, Canada, U.S., Mexico. For example, last December in a trilateral energy ministerial, we signed an agreement to improve energy data integration across the three countries and that is well along and moving quite successfully. So those are some of the issues. We also discuss other environmental questions. We involve job issues and workforce development. We address citing issues for major infrastructure. But I think that's a pretty good and comprehensive kind of overview. And as I said, we are looking forward now to an intense period of working with Congress to see if we can't move forward with bipartisan Administration, Congressional legislative approaches, to address some of these urgent energy infrastructure issues. So again, I would like to turn it over to Jonathan Pershing, who will kind of give a little more flavor and color to a few of these recommendations. Thank you.

>> JONATHAN PERSHING: Thank you very much. I just want to put a couple of slides on to show some folks some of the kind of background, data and information that underpin some of these conclusions and results that we have reached. I won't go through this. This is the kind of background that the Secretary just spoke about. The production issues, the policy developments, the kind of changes. The background, again in the front piece of the report, it notes that as a result of a Presidential Memorandum authorizing as the Secretary has said the White House to chair and the Department of Energy to support a process involving more than 20 agencies around the Government. This figure is -- shows up in the front of the report for those who have seen it, and in some ways it provides a bit of a framing for what we tried to do collectively. If you think about the underlying issues, they fall into an economic competitiveness, an energy security and an environmental responsibility framework. And that's the big circles around the outside. And then you've got a set of objectives which is to generate and yield an energy infrastructure for the 21st Century that's kind of at the center, and then around that you've got the buckets that the Secretary spoke about, the buckets around resilience, the buckets around modernizing the grid a security bucket, and the issue of framing some of the cross cutting issues. You of course have the three areas, we worked on liquid fuels and gas and electricity, and then you've got cross cutting questions. Citings, environment and jobs. So that's kind of a framing for the entire document. The Secretary talked a bit about resilience, this figure is one of the ones that's reflective of the diversity of problems we face across the nation. There really isn't a part of the country that's immune. The purple lines reflect large scale hurricanes, storm tracks of large scale hurricanes, the kind of brownish ones a little bit in the center, those reflect tornado tracts. If you're on the West Coast the red and orange color affect forest fires and green reflect earthquakes so in some sense you're not immune no matter where you are in the nation and if we start with that --

>> SEC. ERNEST MONIZ: Let me comment that the need for North American data integration is obvious here since hurricanes don't stop at the border.

>> JONATHAN PERSHING: Apparently they do in the figure that's created. If you start with that kind of framing, and look at the increased intensity of precipitation events, you see a much larger share of intense events and total rainfall coming in individual intense events, you'll see the consequence of a combination of flooding, surge, sea level, what you've got here in the figure at the top, those are the locations of substations in the electric power sector and you start thinking about what that looks like. The colors reflect various levels of sea level rise associated with climate change, so even today you've got storm surges that's in the blue. If you add a little bit sea level to that, that storm surge plus sea level generates significant impacts in

even more areas and this figure reflects at the bottom the number of individual events that cost more than a billion dollars each. So this is by number. This is unique events, and you can see a largely increasing trend over time. At the same time what we've got is some question about what does that do? It yields outages in the electricity sector you see the trend on the left side that's weather events in the line at the top. Other events largely unchanged. Weather events are what's going up, and on the right side you have these three figures what you see in yellow are weather events, in the center in blue, those are component failures, and on the right that's physical attacks. The left of the two figures. That's the number of events, but the right is the number of hours of outage, and it turns out the hours of outage are almost all a function of changing weather consequences, so here you see really interesting dynamics moving forward. I won't dwell on this is the electricity workforce we have a number of other workforce components, we see potential for significant retirements going forward throughout the workforce. We also see new investment, and this whole discussion we went through a peak of course in the '60s where we really built out our system. Had a period that ran really from the '80s into the early 2000s in which we had little investment and now we're now seeing increase in investment and it's being heavily driven by reliability and the concern for adequacy of reliability is huge, the second larger driver is the effort to integrate the renewables. Here the things the utility community is telling us are the basis for their interest in increasing capacity. Turning over to the second bucket the Secretary spoke about some of the growth in oil and gas infrastructure, the development there. On the left side, what you see are the figures reflecting the reversals of pipelines. We used to generate a substantial amount of our domestic requirements from imports. We had pipelines running from the Gulf Coast to the interior, we're now producing oil and gas in the interior and running to the Gulf Coast that's where the refineries are, and they are equally subject to some of the hurricanes and storm surges, they are coastal in many cases. The consequence of this leads to a number of things, one of which we have potential congestion questions, the second of which may create issues around the SPR, this is also where our SPR is located. You see here a second possibility, this is the congestion pricing that you've got inside the natural gas sector. When you have significant variation across regions in terms of prices, there's significant incentives to build out new infrastructure to provide for transmission. What you see on the far right side that's currently the New England consequence. Where you see much, much higher prices in New England that's reflected here in that figure, but the difficulty of creating new citing has led to the governors of the regions coming together to try to find some ways to manage those kinds of constraints, but you see historically where when you have build-out and the bottom blue line reflects build-out in Wyoming when the build-out happens the price differential declines and you get this tightening and there's not a whole lot of differential across the space. The Secretary also spoke about the question of distribution lines. On the right side of the two figures in gray, the yellow dots reflected in Boston are leaking distribution pipeline networks. And on the right side that's

Indianapolis, so if you live there you're doing well, if you live in Boston, I'm sorry to say Mr. Secretary you probably should move, it's not a great place to b, leaks are quite significant, and on the right side the histogram shows the number of years that it's going to be at the current rate of replacement before those pipelines might be fixed. Philadelphia at the top more than 80 years before the pipeline would be fully replaced at the current rates. The Secretary talked about costs. We have estimated \$270 billion for replacement costs, largely in major cities the larger older cities on the East Coast but major cities. Talk about the SPR I won't dwell on this but the issue of getting oil on the water we have these questions around the new capacity and congestion questions. these certainly are reflected in the report. We have also got significant questions around shared infrastructure. This graph on the top shows what you've got of crude oil loading and unloading capacity, you see the dots in the northern part, we had only about a half a dozen or so in 2010, and three years later you see the extent of the rail loading and unloading capacity throughout the nation reflected here just in the number of crude railcars carrying petroleum, you have a couple of thousand back there in the year 2009, and you have over 130,000 in the year 2014. The rate of growth is extraordinary. And it's reflected then in congestion, reflected in environmental constraints and concerns and inadequate infrastructure, but also reflected in competition. This particular graph on the bottom right shows the location of the Powder River basin which is the supplier of a substantial amount of American coal and runs across some of those exact same train tracks, train lines that you've got which you now need to provide for oil, and oil is a good paying customer, it's year-round, it's 24/7. Coal is often seasonal, but we're seeing constraints in which capacity of available coal in some plants providing electricity has been down to a few days, leading us to significant concerns. Another one The Secretary talked about some of the infrastructure in our waterways. We've got design criteria that call for 400 foot wide channels 40 feet deep, the reality in some cases it's not able to be maintained adequately. The Corp of Engineers seeks to do this as well as it can, but some of the Mississippi basin sediments rapidly and you have constraints there. We have anecdotal evidence that in many cases tankers can't pass each other leading to enormous congestion and perhaps in some cases scraping along the bottom as they go up and down these channels. We also have a concern in which we have unavailability of our inland waterway system through locks and dams, you have the number of hours of outages -- number of hours of outages in thousands of hours 150, 180,000 hours of locked outages around the nation, many of these locks and dams 100 years old. North America, the Secretary talked about this as well, a key component here. Look at the figure on the right. You can see the size of the trade by different thicknesses of the arrows. The purple arrow reflects trade in petroleum and liquid fuels. The orange arrow reflects trade in electricity. Then you have the trade in gas. So significant in both directions, both north and south of the border and growing. Electricity particularly with us and Canada really completely integrated and offers real opportunities going forward, so if the objective here is to build this reliable and safe energy infrastructure, the QER tries to focus on

them, and then this is just a short version of some of the key points the Secretary outlined in his comments with some of the figures and directions the grid of the future, energy infrastructure and security, the resilience and safety and assets recovery points, the shared infrastructure issues and some of the market integration questions. Thanks very much.

>> SEC. ERNEST MONIZ: John let me add as a last footnote, I think it's pretty clear. But just to say the obvious is that a lot of energy infrastructure was built out in the '60s and '70s. In other words, we're talking about 50-year-old infrastructure. Also, especially in the '70s because of the oil embargoes, et cetera, a lot of policies got put in place. And so all we're saying is that the decisions -- infrastructure investments tend to be long lived. Decisions made back then, we are living with today. And similarly, decisions we take today -- and I want to emphasize decisions we don't take today we will be living with for quite some time. And that is -- that would be extremely unfortunate particularly as we face climate risks, as we face tremendous technology-driven opportunities for modernizing the energy system. Partly to meet our climate challenges and partly to lubricate the economy and improve our security, and another long story could be on collective energy security but I'll end it there. Thank you.

>> JOHN HOLDREN: Well, thank you, Ernie and if I can just abuse the chair for a moment by underscoring your last point. I have found over the years that the single most misunderstood aspect of the energy situation is that people imagine if you decide today you want a different energy system tomorrow, you can change it overnight and in fact you cannot. The -- my current estimate of the capital investment in the world's energy system, that is all of the power plants, transmission lines, pipelines, drillings and so forth is about \$25 trillion, and that \$25 trillion investment turns over with a characteristic time of 30 to 40 years, the average lifetime of major energy facilities. And that means basically if you want the energy system in 2050 to look very different than it looks today, you better start changing it now. This is the stark reality of the amount of inertia that is in our energy system. So it's great that the QER has taken this forward-leaning look at what we need, and when we need it. And how we need to be investing now if we want the transmission storage and distribution infrastructure of the future to be what we need it to be. Let me now open it up for questions and comments from other PCAST members and I'll start with Maxine Savitz.

>>MAXINE SAVITZ; thank you, Ernie, thank you, John, for really implementing what we all put on paper in 2010. It's nice to see the first installment come. And also having a really good analytical base. And both your last comments and John's lead to my question. As you go into

the next implementation parts of it, which will in some way handle supply and demand, whether it be all with generation and end use with transportation and the like. As I understand it, a lot of the analysis for this was done up to 2030. And when we're looking at the infrastructure for the generation, we look at infrastructure for buildings, these are all going to -- many that you start now will be here beyond 2030. We have the climate mitigation. We have scenarios by states. I come from California where we have goals of 80% by 2050, 40% by 2030. Will your next installments look at scenarios beyond 2030, as you look at what's going to be needed and what technologies are there already? What policies and the like?

>> SEC. ERNEST MONIZ: Thanks, Maxine. First of all, in the prologue to your question you mentioned the word implementation and I do want to just emphasize that now we and The Administration broadly have two tracks to follow. One which is what you were implying which is the next installment of the QER but I don't want to lose sight of the fact that now moving forward on implementation of the first installment is critical. Part of that is as I've already alluded to working for example with Congress or with the private sector as well of course, and certainly I should emphasize states. We have a tremendous emphasis on the need to work with states. But working on legislation, working on budgeting, on resources for execution is going to be critical. Also analyses, again one example of an analytical area that really needs to be addressed, we all know this but now we need to really look at it. And that is the whole issue of valuation of services in the power sector, distributed generation and storage. We can go on and on. Efficiency. We know that we do not have a regulatory system certainly nationwide. We've got capacity. Capacity is another one. Many, many of these factors are being challenged by the technology evolution. And we desperately need in my view to carry through that kind of analysis, as well, to permit the kind of technology evolution we want. Now, going to your question, 2030, yes, so the -- by agreement -- agreement I mean within the Administration, we decided to really have a focus on 2030. 15-year horizon obviously. And -- because you know, in the end, the view is that what we really want to do obviously is to influence decisions to be taken over the next few years. But have decisions taken with a view to a longer perspective so that we are enabling the kind of futures, and I have to emphasize plural, futures that we think would address our core needs. Now, we did have some analysis that went beyond 2030 in this first round. I think moving to the second round, that remains an area of discussion. I think inevitably we will have a stronger focus on the long return. One important input to that will be the results of this parallel quadrennial technology review approach, which is hopefully by the time it comes out, will not be hopelessly out of date because one year has passed since one has looked at the cost performance of various technologies. But I think that technology review inherently points us to the longer term, as well. So anyway, that remains to be discussed. We

would love to get input from PCAST in terms of the entire design of the next -- of the next installment just as we had input for the first.

>> JOHN HOLDREN: Thanks, Rosina Bierbaum.

>> ROSINA BIERBAUM: Thanks very much, congratulations. And I'm happy to hear the answer to Maxine's question because of course what makes sense for the next 15 years might possibly preclude or limit what could happen in the next 30, 40 years in a disruptive sense. Jim and I have a question about the role of small scale distributed electricity and resilience and it looks like you ran at least one scenario to accommodate high deployment of low cost distributed energy and your answer varies by region. But we couldn't quite tell what the answer was on resilience. So if you could answer that. And then since I already have the floor, you had one of six cross cuts in your budget that were focused on this energy water nexus. And I wonder if you could just explain a little bit the kind of analyses that might be coming out of that particular area over the next year or so.

>> SEC. ERNEST MONIZ: Yeah, I'll talk as well on the DG part. So again there's no question that in our looking at it despite the 2030 horizon, that we see distributed generation as certainly a very important ingredient, although, again, at least my view is we have to go forward with that. And other issues, acknowledging the uncertainty as to how the world will actually evolve in this way. And as you implied, I personally believe that we will see rather different, hopefully all low carbon solutions. But we will see different solutions in different parts of the country. And certainly in different countries in the world. So I think, again, there's this question of robustness. Now, I think personally that a big part of this robustness is the full integration of control sensors I.T. into the system. That's important for liability. It's important for enabling integration, particularly let's say solar. Distributed solar. It's also important for potentially opening up new services to consumers. And I won't go into -- I'll let Craig discuss if he wants the import bill and the increased cyber risk as we take advantage of those opportunities. So again our view was that the job here was to lay out the directions that would enable these solutions, but not in some sense be based upon that being the reality. Jonathan why don't you pick up on the DG analysis specifically and then I'll come back to your other questions.

>> JONATHAN PERSHING: Thanks very much Rosina. Just two observations to add some color we ended up running an effort looking at DG using a proxy of solar as a distributed resource, so that's the first way we framed it. We used a series of model results, part of the work that NREL had done, part of the work with InTech with modeling on the transmission side to try to generate that. There were a number of pieces we tried, we tried a scenario in which you constrained price in all regions. We also looked at the capacity we currently had for transmission across our existing structure. I would as a side note here say we don't think we have really good modeling capacity we think there are real constraints to model in detail the distribution networks and links back to transmission so we put into the recommendation to build it out further but within that we took what we could do we tried looking at that and the regional differences that we found were in those areas where even with a reduced price of solar which is how we induced additional capacity we still ended up with less build out. So we had high build out for example in the southwest, we had significant build out in the west. We had frankly less build out in the northeast and therefore that's where the transmission change went. At the same time what we ended up looking at was what the current expected transmission growth was going to be. So we don't assume a static case in the baseline, we assumed the baseline would be growth already and that that would continue, so the delta we were seeing is above and beyond the growth that we were seeing historically over the last few years, which we project to continue in the baseline. That's where the regional pieces came out that investment is already happening because of existing congestion, therefore the regional differences are in some ways further expanded or exaggerated because of those constraints and structures. I can talk about it further if you would like.

>> SEC. ERNEST MONIZ: Just to note again in terms of my view still uncertainty as to how the world will develop here. In terms of solar, the continued dramatic cost reductions can be a huge issue here, but also there's been a flurry of discussion over the last few weeks about the integration of distributed solar with storage. For example, as something that I think we did not really look at in any depth. That's another example of an analysis that I think could be a game changer for this whole business. That in turn of course, if it is a game changer in terms of deployment levels, it will be a game changer for utility models and how costs are allocated which goes back to the theme about we need to seriously understand valuation of different services to the system. Briefly on energy water, which was your other question, again the focus of this first installment on transmission distribution storage did not have a tremendous focus on energy water. But A, we do think it's very important as you said it's in our budget as one of the six cross cutting themes for expansion. To the extent to which we go much more especially on the supply side, the energy supply side, in the next round, then the water issues will come into play much, much more strongly.

>> JONATHAN PERSHING: Only to add one more point, and Dr. Holdren was the person that did this but Secretary mentioned 14 public session, one held in California, Dr. Holdren chaired it on energy and water especially as it went to the QER, it doesn't get picked up as much because we ended up with a slightly different domain it is reflected back in comments that we got from the public community as well as in some of the background material.

>>SEC. ERNEST MONIZ: And there was no issue about the intense interest in this both domestically and internationally.

>> JOHN HOLDREN: Yeah, I might add that to underscore this is the domain, the intersection of energy and water, and also with climate change that our Chinese colleagues and our Indian colleagues are very interested in pursuing jointly with us. Let me call on William Press.

>> WILLIAM PRESS: Thanks, John. So both you and John have made the important point that the time scale of the infrastructure and the capital investment of the infrastructure has these very long time scales, but at the same time. historically we have these shocks that happen on much shorter time scales. I don't mean natural events like hurricanes, but things like the oil shocks or the quick rise of hydrofracking, or one you just mentioned the possibility that our costs for battery storage might be down by an order of magnitude or two orders of magnitude conceivably. So you can fight the past war and look at the things that have already occurred, but it seems to me you simply can't anticipate whether there are more of these. There will be more of these few year time scale things ahead. It could be a period of unexpected solar activity in solar flares, or it could be unexpected rapidity with which Europe looks west for its energy supply instead of looking east. My question is really how do you build this kind of robustness into the models that you have so that if there are actually large excursions in a dimension you didn't anticipate, you're planning on these very long time scale things isn't completely useless.

>> SEC. ERNEST MONIZ: Well I think in terms of the modeling, I think the best that we have got to offer at the moment has been scenario based modeling with a whole variety of different assumptions. We already do that in terms of the kind of macroeconomic kind of modeling. For example, one of the areas that we are focusing on right now, which is kind of analogous to what

you are saying is we have a variety of technology aggressive scenarios, where we put in various levels of anticipated improvements in kind of the cost performance space for technologies. And without saying too much at the moment because we're in the middle of a lot of this, I'll just say that what we find is that more than -- much greater than the impact of "quote" merely great progress in terms of cost reduction let's say of technologies or not having that but advancing policies, what we find is that when you combine the kind of innovation driven aggressive performance scenarios with modest policy actions, you can get a huge impact. So that's the kind of scenario modeling that we have done and are doing to try to inform that. But the reality is that, you know, investments in the infrastructure just cannot be kept being put off for reasons that we have indicated. And so robustness of the current investments and how policy in particular for us, Federal policy or working with states, how we can influence that is very important. Again, I personally think and you may have different ideas and other ideas, which we would love to get. But I personally think that especially on the electricity side that we just are scratching the surface in terms of what we can do in the I.T. world. And that I believe is a big part of robustness in terms of what comes on. And the other area and we have discussed it with some of you before is a -- they could be a -- there could be a significant change in the transportation sector both technology and business model coming together that could be one of these big transformations. But in the meantime we have to do the best we can to help guide the investments. Because they are needed today. Jonathan you have something to add.

>> JONATHAN PERSHING: Only one narrow point we did try to run a couple of black swan events to try to model some of the scenarios we put into the QER for example we did interruptions of oil supply to take a look at what the consequences would be in the current distribution network particularly with respect to the SPR, we didn't try runs in which we cut off significant amounts of electricity, we didn't try those, we did very, very aggressive new gas numbers well beyond anything that's been projected, so we did try a series of those. They are reflected in these kinds of assessments.

>> SEC. ERNEST MONIZ: Just to emphasize you mentioned Bill both oil from the point of view disruption, and from the point of view of production implicitly by saying hydraulic fracking and just to emphasize the latter, the extra 4 million barrels a day in the United States with different geographies than have been traditional, there's a great case where the infrastructure was not ready, could not be ready in a certain sense, and has really caused some real challenges and bottlenecks. So anyway, that's what we're doing.

>> JOHN HOLDREN: Okay. Michael McQuade is next.

>> MICHAEL MCQUADE: One of the benefits of putting your flag up and waiting a while most of the stuff gets talked about. I just want to reiterate a couple of points. I think if you look at hydraulic fracking, if you look at solar, we all have the benefit of living through a time when these things have suddenly become much more important and much more significant than before. As you said, I think the issue of storage is at that same break point right now. Electricity storage. And whether it's distributed storage or what we call grid scale storage or what we might even call ultra grid scale storage, I think the necessity of very hard examination of what can be done on that in the QTR, but also the sort of output from this report is how highly integrated that is into transmission strategies distribution strategies, and the like to me that strikes me as a very big opportunity in front of us both to make things better but from an analysis point of view. The related question may be triggered what Jonathan said, Jonathan you do these things typically where you push the boundaries of where things might go in one dimension and look at what happens. You look at maybe some black swan events. So take a big step back. Can you say what you think are sort of the most sensitive areas in the forward projections here? I mean, should I go to bed thinking that sort of the integrity -- that's not the right word. That the quality of analysis sort of mostly depends on whether oil doubles, or should I go to bed at night thinking it mostly depends on what happens with solar. Do you have a feel for the most critical elements of the integrated analysis are?

>> JONATHAN PERSHING: Let me offer a couple of observations, the first one I think none of them, if I had a halving of the oil price or doubling of the gas production, the system looks like it's going to creek along, it won't be very efficient it won't run very smoothly we'll have a whole series of constraints on the margins and if we let it go for too much longer it will get worse and worse, so I think a lot of those fall into that category. The ones I'm somewhat more concerned about frankly are the climate change events which I think we're starting to see. I think we're seeing these disruptive activities that we look like we're seeing increasing probabilities on and those look like they will be in places that are already fairly vulnerable, East Coast cities, production centers in the American, south that whole thing. The second one which I see significant constraints in the electricity sector have to do with cyber risk and I think that's a significant increase in vulnerability and I look at that in part as we increase our electrification, because that's a tendency and trend we are already on and plausibly elevates the risk instead of reducing it, so those are the kinds of things I see we didn't do the analysis with those in mind, so there might be others but I picked those two.

>> SEC. ERNEST MONIZ: Let me add a point, first of all, I agree with Jonathan's initial point that things like the factors of two change in price, et cetera are significant, I remind you in that particular case, for example, over this last year, we have run that movie. And I think it kind of emphasizes that this certainly leads to distributional questions. But if you look in terms of implications for the system as a whole, it's not revolutionary. In fact, by the way in the United States, despite the price reduction, you know, we expect to produce several hundred thousand barrels of oil a day more this year than last year, so I think these things are huge shifts at the level of firms, of companies. And often impact societies locally, et cetera. But I think we're pretty robust to most of this borrowing -- actually I think that in the end, the bigger thing -- a bigger potential disruption may come from some really out-of-the-box technology development.

>> JOHN HOLDREN: Well we are amazingly on time. I see no more flags up. It is about a minute and a half before 10 when we turn to our next topic. So I can only thank Secretary Moniz and Dr. Pershing for their presentations and the great Q&A session we just had. And larger thanks for the amazing work that went in to producing the first installment of the QER which as you graciously noted was a joint venture really between the analytical secretariat at the DOE and wider agency process in which lots of folks across more than 20 departments and agencies took part, so I think this is just what PCAST had in mind in late 2010 we first called for section exercise. I think folks can feel really good about the product. And I think we all know that rule of thumb that as much work goes into a report, you need to spend at least as much afterwards working to see that the results are implemented. And I know that all of us will be engaged with you in making sure that that happens. So thank you again for all your work. (Applause).

>> SEC. ERNEST MONIZ: My Public Affairs Director says you can't step on the applause line. But I just want to say we're also quite serious about the charge to PCAST in terms of giving us your thoughts in terms of the path forward. We appreciate it. Thank you.

>> JOHN HOLDREN: Great.

**Precision Medicine Initiative:**

>> ERIC LANDER: Great. While our guests are getting settled, let me just remind us now that we're switching from the QER to the President's "Precision Medicine Initiative". As PCAST will remember on January 30th of this year, President Obama announced a Precision Medicine Initiative. To take advantage of the extraordinary opportunities that have been presented by technology in medicine to really gather large amounts of data and in the long run turn our health care system into a learning system. That is a tall order because it involves collecting all sorts of data, genomic data, nepogenomic data, microbinomic data and wearable data and other sorts of data to figure out how we can integrate those data and solve our interoperability problems and learning problems, and it's a great challenge. The President channeled many people in recognizing that there were opportunities across the entire health care spectrum with regard to common diseases that affect everyone from heart disease all the way through cancer. There's been a lot of work to follow up on that broad direction the President said at the end of January, and we're going to hear today an interim report on many of those activities some of which are within the Federal Government. Many of them in addition are activities going on just outside the Federal effort in the extraordinarily active biomedical sector, both in academia and industry. We have a great panel today and we are going to start off with our own Tania Simoncelli, Director at OSTP, who is going to give us a broad overview of the Precision Medicine Initiative. We're then going to hear from Richard Lifton the Sterling Professor of genetics and indeed he is a Sterling Professor of Genetics at Yale University in the Howard Hughes Medical Institute and Rick somehow agreed to be one of the co-chairs of the NIH committee that is scoping out this Precision Medicine Initiative and we're grateful to him to let us know about how that's all going. We're then going to turn to Todd Golub who is my own colleague at the Broad Institute. He's a professor at Harvard Medical School in the Dana Farber Cancer Institute. And he is an expert on many aspects of cancer, particularly cancer genomics. And then we're going to turn to George Yancopoulos, representing one of the most active efforts in the private sector connected to precision medicine; he's the president and chief scientific officer of Regeneron Laboratories and I'm sure he'll share with us both activities they are involved in and his broader view of what's happening in the industry. So Tania if you would kick us off.

>>TANIA SIMONCELLI: Sure thank you Eric and thank you to all of PCAST for inviting us here to talk about this important initiative. As Eric mentioned I'm going to kick us off and give a broad overview of the President's Precision Medicine Initiative that was launched back in January. So first of all, what is precision medicine? We have defined it as an emerging approach for disease prevention and treatment that takes into account peoples' individual variation in genes, environment and lifestyle. Precision medicine really isn't a new concept. Doctors have long

understood that individuals differ in the way they experience health and disease and respond to treatments and have always sought to tailor treatment approaches to take into account individual differences. With that being said, most of the treatments or therapies that were available today really were designed for an average patient. And the problem with that is as a result, many therapies don't work for many people. So precision medicine is really about moving away from this one-size-fits-all approach. It seeks to harness developments in big data in genomics and other advances in science and technology to better understanding the underlying mechanisms of disease and human variability and to apply that knowledge in the development of more effective individualized treatment strategies. Precision medicine is already here, we've seen some really dramatic successes over the last few years, especially in the area of cancer treatment. And there have been some new developments in this field that have saved patients lives and have dramatically changed their quality of life. Just to highlight one example, and you can read about some of these stories on our Web site, Bill Elder was diagnosed with cystic fibrosis at the age of eight, and at that time the life expectancy for CF patients was very low, like mid 20, and now Bill is 27, and he's not only alive but he's experienced almost a complete reversal of symptoms of cystic fibrosis, which as you may know can result in repeated visits to the hospitals to have your lungs cleared because mucous builds up in your lungs, and can cause all sorts of follow-on complications. The reason Bill is doing so well is because of a drug Kalydeco that was approved by FDA a couple of years ago for the treatment of the particular form of cystic fibrosis that Bill has. Kalydeco is a pretty remarkable drug because it's the first drug to treat the underlying cause of cystic fibrosis, rather than the symptoms by helping to actually restore the function of the protein that's made by the impaired genes. The Precision Medicine Initiative aims to make stories like Bill's the rule rather than the exception in care. It was launched by President Obama as Eric mentioned on January 30th. At an event at the White House where he was joined by approximately 200 patients and patient advocates and researchers and industry and tech company representatives and bioethicists and privacy experts and others. The mission of the Precision Medicine Initiative is to enable a new era of medicine through research and technology that empowers patients, researchers, and providers to work together toward development of individualized treatments. And you might say why are we doing this now? Well, there are really a number of key elements that make the idea of making precision medicine the rule rather than the exception, that make that vision possible. And these things are really at a point where they are starting to align for the first time. And these include advances in genomics and other -omics. The adoption of EHRs by hospitals and clinicians. Advances in data science and bioinformatics. Innovation and mobile health technologies and other technologies. And the fact that patients are more united than ever before. They are more engaged in research. They are more sort of -- there are more sort of examples of extraordinary partnerships between patient organizations and pharmaceutical companies and foundations like the Kalydeco example is one of those. So we sort of entered

into this space where these forces are starting to align in new ways. In addition to that, of course, the costs of human genome sequencing. I'm sure many of you have seen this slide, have declined dramatically and of course that also makes doing this at a larger scale since genomics are one of the key technologies that can make precision medicine possible, so the notion of doing this on a large scale is also becoming economically feasible. This is another slide that sort of talks about where we were ten years ago in terms of things like cost of sequencing and time it took to sequence was, the human genome it took two years ten years ago, and now we can do this in less than a day. EHR adoption, we were only at 20% to 30% ten years ago and now we're more than 90% in terms of providers that adopt EHRs, et cetera, computing power, et cetera. So the vision of the Precision Medicine Initiative is to build a broad research program to encourage creative approaches to precision medicine, test them rigorously, and ultimately to use those to build the evidence base needed to guide clinical practice. In the near term, the goal is to apply the tenets of precision medicine to a major health threat, namely cancer, in the longer term to generate the knowledge base necessary to move precision medicine into virtually all areas of health and disease. So what are the core components? There are really three core components of the initiative that was launched back in January. First is the -- a cancer component that NCI is leading. That's focusing on expanding genetically based cancer trials, exploring aspects of cancer biology, identifying new cancer subtypes and therapeutic targets, and ultimately creating a cancer knowledge network to generate and share new knowledge and to fuel scientific discovery and guide treatment options. Secondly, the Precision Medicine Initiative aims to create a national research cohort of 1 million or more Americans who voluntarily agree to participate in research. And the vision here is that participants will have the opportunity to contribute vast sources of data, including medical records, genetic information, environmental and lifestyle data, data from mobile devices, et cetera. And that this data will be broadly accessible to qualified researchers. And really the vision is that this will -- the creation of this cohort will forge a new model for scientific research that emphasizes engaged participants and open responsible data sharing. And finally, there's a component of the initiative that's focused on regulatory modernization. And the idea here is to identify and support regulatory changes that will advance precision medicine and protect public health, and one thing that is very much underway right now that the FDA is focused on is the development of a new approach for regulating next generation sequencing technologies, since this is such a key technology that is relevant to the precision medicine space. So where are we? There are a number of activities that are -- that have been set up since we have launched the initiative. First there are a series of cross Government working groups that involve a range of agencies. Not only HHS agencies but also -- and the Executive Office of the President, but also the VA and the Department of Defense. And these working groups are focused on a few key areas. One is participant engagement. Another is stakeholder outreach. We recognize fundamentally that this is not an initiative that -- this is an incredibly ambitious initiative. It's not one the

Government can do alone. So there's quite a bit work going on to reach out to other stakeholders in this space, and to look for opportunities for building partnerships. Data infrastructure will be key. And I'm sure Rick will also talk about what the advisory group is doing to think about the cohort design. Regulatory modernization as I mentioned and privacy. One of the commitments that we made in launching this effort is that we would take steps to build privacy into this initiative from the start. And in particular in the design of their research cohort, and I'll say a couple more words about that in a minute. And then the second group of activities that Rick will talk about are -- fall under the NIH Advisory Committee Working Group that's working to develop by September recommendations on the cohort design. So just a quick word on privacy. As I mentioned, the White House committed at the launch of this initiative that we would make sure that protecting patient privacy is built into our efforts from the start. So very soon after the launch, OSTP organized a series of roundtable discussions with bioethicists and consumer and health privacy experts and others to identify some of the key privacy and related issues and concerns and opportunities that we should consider in creating a national research cohort of a million or more Americans, and we have since set up an interagency Working Group that's now building on some of those preliminary discussions to develop a set of privacy principles to guide the development of the PMI cohort. I should also mention, we were quite happy that PCAST had taken a deep dive into some of these topics in their big data and privacy report, and some of the other reports and those have been extremely helpful in jump starting this process. We're also -- this group is also working to identify gaps and other issues in current privacy and security protections and propose policy changes to address those gaps. So I'm going to turn it over to Rick from here so he can give some more details around the NIH process.

>>RICHARD LIFTON: Great. Thank you, Tania. And thanks to PCAST for the opportunity to be here today. Let's start by pointing out that if you go to your today for a baseline evaluation, the analytes that will be measured, things like sodium potassium, creatinine, liver function tests, CBC to measure your white cell counts, your red cell counts and platelet counts are pretty much the same set of analytes that would have been measured 60 years ago, and we have added modestly to that and what has been added has come in part by identifying biomarkers that are predictive of future disease. So the big successes have really been in the cardiovascular arena where we now know that hypertension and high LDL cholesterol levels are predictive of future heart disease. And if you lower those biomarkers, you will actually reduce the incidence of disease. However, if we think about where we need to go with the future, with current epidemics looking to the future of neurodegenerative diseases such as Alzheimer's disease, diabetes, and inflammatory diseases, and autoimmune diseases we don't have any such predictive biomarkers for these disorders. As a consequence, we wait until patients actually develop disease and then hope we can prevent further progression of disease. But we really are

not typically able to cure these disorders. And we would think we would do better if we could intervene earlier. So I think this is one of the opportunities in a national cohort study going forward is to try to identify new biomarkers that would be predictive of disease with the expectation that if we can identify specific patients who are going to develop disease, that we will develop a better understanding of the causation and the pathways that contribute to these diseases. And therefore, be able to intervene earlier with better therapies. And I think the cystic fibrosis example is a contemporary one where we understand the specific causes of disease, we're able to go in with specific therapies that are directly tailored to the underlying abnormality. So the idea that's been put forward is to develop a national research cohort of about a million individuals that would enable us to develop new predictive biomarkers of disease. And I think the timeliness of this as Tania indicated is that we have whole sets of new technologies that we're really -- that were really almost unthinkable even ten years ago. The genomics you all have heard a lot about but also measuring metabolites in the blood which are billion integrators not just of our genetic constitution but of our environmental exposures and we can now comprehensively analyze metabolites in blood in ways that we couldn't previously. We can measure what is happening in the immune system at the level of single cells as well as whole populations of cells to think about and understand in better ways what the immune system is sensing and what it's reacting to and hopefully think about what its actually doing. Again, opportunities that five years ago, we weren't really close to. We can measure bacteria in our intestine, which surprisingly vary across conditions and may be predictive of disease and may actually be contributing to variation in health and disease in the population. And then lastly in cancer, for as many advances as Todd will tell us about that have been made in cancer, we still are waiting until we can find a tumor. The opportunities to actually measure mutations that are appearing in the blood that are being shed by early nascent tumors provide the opportunity to identify these mutations before the cancer may be fully developed. And these of course are opportunities for really early intervention before a full-blown cancer may even have developed. So for all of these reasons, it seems like a good time to revisit a longitudinal cohort where you would identify a large body of individuals who are willing to participate in a new cohort study starting with people from the population who have not yet developed disease, follow them longitudinally over time, and as they develop particular end points, correlate those with particular markers garnered from these various types of data. And as you can imagine, as Tania indicated, this requires very large datasets analysis that's capable of capturing all of the data, and analyzing it jointly. And so the types of things we can think about include identifying preclinical biomarkers indicating risk. They also can enable us really for the first time to address response to therapy. And as Tania indicated, we treat everybody with high cholesterol and hypertension ostensibly the same. We realize there's wide variation in the response to individual drugs. But we have not had large enough cohorts to really systematically monitor how individual patients respond to individual therapeutics. And this I think has the potential,

this scale of cohort, to provide insight into this. And of course on top of this, the interaction of genes with our environmental exposures, we now have ways to do a far better job of measuring our environmental exposures. If you simply think about one of our major environmental exposures is our diet. Well, our diet in the efforts that we have had to date to measure diet, basically what do you recall having eaten over the last month or week or year.? These are notoriously inaccurate assessments and I think if we asked everyone around this room, what did you eat this week? Or what did you eat for breakfast even, that might be a challenge for many of us to come up with. I know in my case that would certainly be the case. So there are better ways to capture this data in an automated fashion. And the advent of electronic medical records obviously adds to it the opportunity to in a relatively automated way, capture the totality of one's health care exposure and involvement over long periods of time. So I think the opportunities are quite spectacular for a new cohort study. But there are many challenges that go along with thinking about this opportunity. And many of the questions that will have to be dealt with and wrestled to the ground will be who should be included in the cohort. And the who includes many dimensions, ranging from should we start with adults; If we should start with adults, what age range do we want to start with? We know that the age at which people develop disease and ultimately go on to death is getting later and later. So do you want to start -- how early do you want to start is dictated by how long you are willing to wait to see the outcomes. These are practical considerations to think about. Should pediatric populations be included in such a cohort? Obviously much of adult disease begins early in life. But is it practical to include pediatrics in the same cohort and the study design that would be required represents some challenges, as well. How do we ensure that the cohort is sufficiently representative of the broad swath of Americans that we can be satisfied that we're doing a good job of measuring the variation across the population. Not just in terms of ethnicity, but also in terms of environmental exposure. We realize that there's wide variation in environmental exposure across the country. And it's not evenly distributed. So how we address these questions I think is a significant issue. The how is also important. Should we start with existing cohorts which were ascertained typically in the pre-electronic medical recorder era, really a laborious collection of data from individual patients capturing all of their doctor visits to different physicians who may not even be in the same health system. Versus starting anew with a closed system like the VA health system where patients get all of their care in the same system, so all of their records can be in an automated way collected centrally. These are kinds of questions that we are wrestling with. And then of course, the nitty-gritty of what to measure in everybody. What things should we only measure in a fraction of people; should we in addition to having a longitudinal cohort ascertain some patients with incident disease in the hopes that we can learn something more quickly. Issues of privacy and availability of data, balancing individual patient privacy versus what we would hope would be wide access to the data to qualified researchers. Epidemiologic studies have frequently struggled with how to make the data available to the wide body of

researchers who might bring something unique to the table. And these are obviously challenges as we think about going forward. So the process that we have undertaken since starting in February has been to bring together a group of experts. I'm co-chairing this group with Kathy Hudson from NIH and Patrick Lake from Duke. And we've been able I think -- we've been quite fortunate that virtually everybody we have asked to join the Working Group has joined. It's a spectacular group from both academia and industry, and a very high-level group. We have convened a series of meetings that are going over specific issues such as what's the cohort design going to be, what are the measurements going to be. How do we capture Electronic Health Records and how do we make sure that the data that comes in Electronic Health Records is actually usable for the kinds of research that we want. As you may know the most frequently used Electronic Health Record is largely built for purposes of ensuring billing compliance and that the maximum billing is achieved. It's not built as a health record per se in trying to figure out how we capture this data well is a major challenge. So, and as Tania indicated, we're on a very short timeline. The goal is to report out to the Advisory Committee to the NIH Director in September. So we've got our work cut out for us. But I'm optimistic that we're on track.

>>ERIC LANDER: So we'll turn to Todd Golub, as I mentioned chairs the Board of Scientific Advisors to the National Cancer Institute.

>> TODD GOLUB: Thank you for the invitation to be here today. In contrast to what Rick focused his comments on which was using precision medicine as a way to think about risk for developing future disease, the efforts in cancer precision medicine at the moment are focused primarily on optimizing treatment. And so a vision for cancer precision medicine looks something like this; a patient comes to the oncologist and the genome of the tumor is analyzed and the mutations in the genome that are observed in the tumor are read out and then used to guide the optimal selection of drugs for that particular patient. Is there any reason to believe that such a thing would actually work? I think as Tania mentioned, there are actually now a number of examples, subtypes of leukemia, subtypes of lung cancer, now major subtype of melanoma which was previously thought to be completely intractable using this genome guided precision medicine approach to cancer is leading to substantial benefits for patients. Most patients not yet cured, but clearly on a path to a completely different paradigm for how to treat cancer patients for the future. So there's reason to be encouraged. But it's reasonable to also ask, are we close to this being routine for all patients benefiting from a precision medicine approach? And here I think the honest answer has to be no. For most patients today, this approach is not practical. It's not that it's too difficult to decode the genome in the tumors. That

may have been difficult a half dozen years ago. But now this has been made quite routine with advances in genome sequencing technologies and computational approaches. But rather, when we can read the mutations of the tumors, we either don't know what treatment approaches would be most beneficial, or we know what they might be but the drugs don't actually exist. So I would like to mention three what I think are significant barriers to the full realization of a cancer precision medicine vision. One, we need a way to learn from the world's clinical precision medicine experience. If a patient today is treated in a particular way, and responds or doesn't respond, there's not really an effective way to know what mutations in the tumor explain that response or a lack of a response. Because there are many mutations in the tumor, any one of which or a combination of which could explain that response. And so what we need to be able to do is to aggregate the data across many patients across the country and ideally the world to make these correlations between particular genomic abnormalities and responses to particular treatment, and we don't have a mechanism to do that and I think that will be critical for the future of precision medicine that will require building an infrastructure to make it possible, and also working on our culture of sharing patient's genomic information and clinical information in a way that respects patient privacy. Just -- it's likely that as many as 100,000 patients in the United States alone will have their genomes analyzed, their cancer genomes analyzed in some form over the year ahead. But few of those will be available to form a learning system. Two, we need to discover all the cancer dependencies and relate them to the genome. What I mean by dependencies is that we know that tumors have particular vulnerabilities, some people call them Achilles heels, that's therapeutic opportunities particular proteins in the cancer cell which if inhibited will cause the tumor cell to die. We need to know what all of those are and be able to relate those to the cancer genome. This just a couple of years ago wasn't even feasible to imagine such an experiment. But it's now possible with new methods in genome editing and other laboratory approaches to make a complete dependency map that would allow researchers and ultimately oncologists to be able to read off the cancer genome. And from that genome, infer what are the therapeutic approaches to take. This -- you can think of this kind of by analogy is that many normal cells have a belt and suspenders kind of approach to survival. And in the process of creating a tumor, the mutations that cause the tumor often disable the belt, leaving the suspenders as a vulnerability in the cancer cell not in a normal cell so that's a therapeutic approach and there are now systematic ways to discover those particular vulnerabilities and we need to have that complete map for precision medicine to really play out. The last hurdle I would think of for the long-term success of cancer precision medicine is that we need healthy drug discovery ecosystem, and by that I mean that we need to have an appropriate match between the therapeutic needs that are encoded by the cancer genome, and drugs that are available. At the moment it's only the minority of those fantastic therapeutic targets that the cancer genome is telling us are important that we actually have drugs for. They tend to fall into a particular class of drugs that are readily approachable by

standard approaches. Classes of proteins called kinases for example. The industry knows how to make kinase inhibitors well so much of the biopharmaceutical agency making cancer drugs focuses on this class. But unfortunately kinase mutations only represent a minor fraction of the cancer genome and we need to figure out how to address the rest. Otherwise, even if we do a brilliant job at making the decoding of tumor genomes routine, sharing all of the information, and understanding the biological implications, if we don't have the right drugs to match, we will have a problem. And so this will require investment in the earliest approaches to drug discovery, including innovative new methods to make it possible to attract those undruggable targets. So in summary I'm enormously optimistic about the prospects for cancer precision medicine. We clearly should not wait for all of these challenges to be solved and perfected before moving down the road. We need to learn as we go. But I think it's fair to say there's still significant work to be done.

>> ERIC LANDER: We'll turn last to George Yancopoulos from Regeneron.

>> GEORGE YANCOPOULOS: Well, it's an honor to be here discussing the exciting potential for the recently announced Presidential Precision Medicine Initiative. I think we all share the dream. Sorry; I guess -- I don't know what's wrong with the slides. We all share the dream about the Precision Medicine Initiative. And what I think the dream entails is what you heard about already. That we can start with the genome and with our genes and we can develop a dramatically new way to promote health and to fight disease. The dreams that we can use, the genome for better prognosis to better predict health risks. Earlier and more precisely. We also help to use the genome to better discriminate between related disease states and appropriately deliver more precise treatments, the right treatment for the right patients. And perhaps most exciting to us as a biopharmaceutical company and related to what Todd was just telling us about, it's to bring important new medicines to patients in need. So the dream is to find genes using the genome, that either cause or predict disease. And then develop new therapeutics based on these genetically defined drug targets. That's the dream. So I guess I was invited to extend this virtual dream into the real world for you. And to tell you that it can indeed lead to major successes. We were perhaps the first company that was based on using the earliest versions of so-called genomics technologies. And it's now the major focus of our company. And this focus in using these approaches have helped us become one of the most successful biopharmaceutical companies of the last five years. Not only in terms of company growth and jobs creation, but most importantly in terms of bringing important new medicines to patients in need. That's what we do. And in terms of our efforts, as I will describe, we have already begun to show that the dream of the large scale Precision Medicine Initiative is real. As

we have already started a very related and relevant effort involving a collaboration between our company and a very forward thinking health care system known as Geisinger Health Systems and I think many who are involved in this process feel that our collaboration with Geisinger can serve as a useful model here for the PMI and perhaps can somehow be incorporated into this NIH effort. Now, the new thing about the PMI that we're talking about is simply scale and speed. We know it works. There's nothing really new about the fundamentals. The fundamentals work. The reasons we are such believers is we were among the earliest users of the earliest versions of genomics technologies using all the same principles, but just much more laborious approaches that took a lot longer, and they worked essentially proving that with more speed and more scale, we'll only get more successes. Our efforts in a rare genetics disease known as CAPs involving collaborations with major human geneticists and academia such as Dan Kastner with NIH and Hal Hoffman with University of California at San Diego, was perhaps one of the first successful examples of developing a biological therapy starting with major human, starting with human genetics data. It's very analogous to the story you heard from Tania and Rick about Cystic Fibrosis, but in this case we brought forth not a small molecule artificial chemical as the drug, but a biologics therapy starting with our own human genome to treat a human genetics disease. And I think that really exemplifies the dream. But one of the biggest stories that we have also been involved in that a lot of people point to as showing how successful this whole thing can be if it's just further scaled is the so-called PCSK 9 story for hypercholesterolemia and cardiovascular disease. It has let us and another company called Amgen to a near term possible treatment for hypercholesterolemia and cardiovascular disease for patients who do not appropriately respond enough to existing drugs such as the statins and in this particular case, it's almost the flip side, but just as important in terms of precision medicine. Gene mutation seen in a few can lead to a therapy that can treat millions or maybe everybody. So the PCSK9 is a great story starting with the gene, and over the course of a number of years, going from that gene to eventually modeling the disease in animals, to eventually developing a biologics based therapy which has shown very impressive efficacy in late stage Phase III studies for both lowering cholesterol and potentially even improving cardiovascular risk. Our data as well as Amgen's in many ways are both quite supportive of this idea, and both of these drugs are going to be evaluated for potential approval this summer by the FDA, showing that these approaches work. As I said, the only major difference from what we're talking about is these prior successes, they are based on the same principles. It's just simply size, speed, and scale that we're talking about. And in terms of this, because we were such believers we a couple of years ago initiated a foundational collaboration, the first of its kind between the leading biopharmaceutical company and a leading health care provider. We have to admit that in this effort, while we like and appreciate what we bring to the table, we think what's most important and unique is the patient resources provided here by Geisinger. It's really the most critical and unique resource; it's a very special patient health system

involving more than 2.5 million people with cradle to grave records, in many cases across multiple family generations. And most importantly, as you already heard from Rick and others here, most records, most cohorts haven't been based on electronic health records that can be digitalized and searched and used as big data. Luckily, and the reason we went to them and chose them to be our partners is they were the first major health system that focused on Electronic Health Records in the early 1990s, and we believe they have the best-in-class and also the best in the field of clinical informatics. So our combined goal with Geisinger was to first build the world's most comprehensive genotype/ phenotype resource combining de-identified genomic and clinical data from over a quarter million people to aid drug development and genomic medicine, totally analogous to what we're talking about here in terms of the Presidential Precision Medicine Initiative. And then the goal is to turn the genomic data into medically actionable information by translating these genetic discoveries into improved patient outcomes in therapeutics just as we did slowly before, we now just hope to amplify and do this on a larger, faster scale. We brought a lot of the upfront technology in terms of scalability and so forth, one reason we were able to do this so fast is believe it or not we build this on the backs of a very related effort we did in laboratory mice over 15 years ago, which really set us up to be able to do exactly the same thing in humans nowadays. So we really have very impressive technologies for speed and automation, but the most important aspect of the collaborations is who we are working with and who we are sequencing with, and the unique advantages of the Geisinger database; they are really we believe the right population for us. We have a collective effort with them to engage their people as volunteers and participants, and our ability to engage with them has been astonishing to me. We have already consented just in the year and a half that we have been operational over 80,000 patients to date. We have greater than 90% consent rates, with a broad consent for research and data sharing. These people want to be involved, volunteer participants and contribute to the common good. From these we have already acquired over 50,000 samples for genomic analysis of which we have already sequenced 40,000 individuals. The numbers have truly exceeded our hopes and expectations. And it looks like we are on target to have done 100,000 people by the end of year. A really astonishing number. The types of consenting people include not only unselected populations suffering from all sorts of the diseases that are of interest to all of us, such as Alzheimer's and Parkinson's, to cancer and cardiovascular disease, but specific subgroups of interesting populations, such as very detailed characterizations of people who have undergone very extensive heart analyses following cardiac catheterization, or enormous numbers of people who have undergone bariatric surgery for morbid obesity, one of the largest such populations in the world. So the real key differentiator is Geisinger is the world's largest longitudinal live population in which iterative callback phenotyping and sample collection are already operationalized, and already linked to detailed long-term electronic health records which makes this I think a really unbelievable opportunity. This slide just summarizes the wealth of

data. Every lab value, every characterization that you would want many times measured per year for individual patients. Almost every disease that you want represented in thousands of patients already in the populations looked at. And this slide here just shows the value of having in-depth longitudinal health records. This just shows a single patient typical in their population, studies over almost 20 years longitudinal readings for their lipids, their triglycerides their body weight and so forth, imposed upon these long-term records, an important medical intervention - gastric bypass. We can see how everything responds to the medical intervention, whether things get better or not, and then we can relate it to the gene, and understand why in one particular case the patient might have had a good response to the intervention and in another case not. Because we have 20 years of records on that patient. And we can follow them and see how they respond. So the other I think important thing for all of you to realize is not only did we start the data gathering and so forth and putting this all together. But it's already started to produce I think very impressive and important insights that can make differences for us. I should mention the company deCODE Genetics headed by Kari Stefansson. They are really the pioneers in this field, this whole area. They did a very important effort in Iceland essentially to try to sequence the entire Icelandic population. We can talk about details of that later. They just had a series of monumental papers published in a nature journal highlighting some of their key findings, but one of the key things they focus on are what are known as human knockouts, people knocked out for individual genes. Also known as LOF or loss of function alleles. Our stories we already told you about the CAPS story the rare disease the PCSK9 this can lead to a treatment benefiting millions of patients suffering from cardiovascular disease all started with these sorts of human knockout stories. Well the numbers in our population today, just the interim analysis of our first 31,000 patients, shows staggering numbers particularly in comparison to the previous standard. In an interim analysis of the first 31,000 people we saw or sequenced, we see more than 25 times as many human knockouts as in the Icelandic population. While they in Iceland found knockouts for only about a quarter of all of the genes in the genome, we are already exceeding loss of functional alleles for more than 90% of the genes in the genome. That means we get insight on almost every gene in the genome for human beings. And while deCODE had homozygous knockouts in only about 1,000 genes, we already see and we are just getting started homozygous knockouts for over 2,500 genes . That is over 10% of the genome already. We are just getting started. This slide in the circles tries to actually show a drawn-to-scale representation of the total number of knockouts in deCODE, that's the small circle, and what we have just already seen in our first 31,000 patients. We have already seen more than half of the knockouts that they saw; they only have seen 2% of the knockouts that we have. And the important point is they have already saturated their population. We are just getting started. We think this is very exciting. And it's working. All of these human knockouts and so forth have already led us to find, for example, in any particular field almost all of the known lipid genes that have been previously associated with human

disease. Just in the first 31,000 patients. Everything that's been done for the last 20, 30 years, we have been able to reproduce and then we've been able to get even more genes, new candidates. So for example, we have a new gene that in certain patients it needs, seems to be associated with about a 25 to 50% increase in their baseline cholesterol levels. And it's associated with the corresponding increase in their risk for cardiovascular disease. This is exactly what we're all talking about. And just to end, we can do the same thing. We can find -- we can start with rare mutations and rare patients. Look at them in the whole population and see where the common variance around contributed to disease in all of us. So we start with rare patients, rare markers and extend them. So my only point is from our perspective, the Precision Medicine Initiative dream is not only alive and well but it's already being turned into reality. We believe that the Regeneron collaboration will serve as a model that's already up and working and yielding results, and perhaps we can even find a way to include it and allow it to help jump start the Presidential initiative.

>> ERIC LANDER: Fantastic. Let me thank the panel for the range of presentations here. We really got a whole swath of the Precision Medicine Initiative. PCAST tends to -- they put up flags when they have questions. I already see several coming up, and I think we can cover anything from some of the fundamental assumptions here to how the Federal planning is going, to what more maybe needs to be done on cancer, to what's going on in industry. I saw Craig, Susan, Jim Gates, and maybe other flags will come up. Craig.

>> CRAIG MUNDIE: Thanks Eric. Thank you everyone. I had a chance myself in the last year to participate in a trial related to some of this. The only difference between the one I was in and to some extent the framing of the presentation today, although George is a little different, is we thought about this as precision wellness. We were not looking at people who had disease. We were looking at people who didn't. Or didn't think they did. Some of the things that were interesting and I offer for your comment, we only did 107 people in the year, and still we found a remarkable number of interesting things. Almost all of the people in the trial had some actionable thing that came from this type of analysis, not in the sense of classical disease intervention, but more in the preventative sense. One of the things we kept being reminded of as we did this was that because it's all about precision medicine and that's sort of N of 1, there's still a lot of framing of this is I'll say more classic epidemiological. Why a million is sort of one question that comes to mind. Then as Rick said we don't even know how to make up what should be in the million. I would tell you it would be interesting to think we might learn more faster by putting together 100 trials of 100 that when we weren't trying to be so careful about this. Because so much of this turns out to be the individual variance. And that that's what the

essence of precision medicine is going to be about anyway. And then the last thing is even in Tania's overview you said well what we want to solve is cancer. I mean we obviously want to solve other things. But a lot of the talk is about cancer. Which you can say is one of the harder ones. And it seems like there's a lot of low hanging fruit, particularly if you focus on this wellness and prevention aspect as opposed to just precision curative. And so I would love to hear everybody's thoughts about, are we still sort of wrapped up in classical thinking of high scale things when in fact a number of even lower scale things might yield a lot. George's comments about well 31,000 it's not close to a million. But wow you've seen quite a bit of stuff, and if it's actionable, can we get the country moving sooner on a wider range of low hanging fruit preventative tasks.

>> RICHARD LIFTON: I'll jump in there, and I think your points are very apt. In fact I think many of us of the scientists in this room have taken precisely this approach of looking for the extreme outliers in the population who have particularly unusual forms of disease to try to identify genes and pathways that underlie extreme forms of disease, and then hope that we can go into the general population and apply those lessons. I think the -- one of the motivations for a larger cohort is specifically to try to identify pre-clinical biomarkers in addition to genetic factors. We're not very good at integrating gene by environment just from the identifying people who have interesting traits, and then trying to decide if they have that trait, identify the genes that contribute to them, that may not help us get very far in identifying what the key environmental interactors are that might be driving the disease in conjunction with the genetics. And I think that's one of the major justifications for doing a longitudinal cohort rather than simply as many of us in this field are doing, are taking a chunk of patients with each individual disease. And that work is clearly going to happen much faster than these longitudinal cohort studies are. So I think the major justification in my mind for the longitudinal cohort is to try to link environmental exposure, other metabolites in addition to the genomics, to the preclinical risk of disease.

>> GEORGE YANCOPOULOS: So I really have to jump in here because we do this all the time. We totally agree that there's a value to what Rick and you are talking about which is very rare, even a single patient with a very, very big affect. We only might need one person to show that, hey, a gene causes morbid obesity. Or protects against some type of disease. On the other hand, what you need to do is then query that against the whole population. And so we do this all the time. We start with the family for example that has morbid obesity, a single child at the age of eight who weighs over 250 pounds. And we find that mutation. But then the next question is how relevant is it across the entire population? Well then we find much more common mutations

that go up and down in the whole population. So some mutations result in people being on average 20 pounds lower in weight and other 20 pounds higher in weight. You wouldn't be able to pick it up in single patients because 20 pounds difference in weight gets lost in the statistical noise. So the power is to go from and combine both approaches. What I think agreeing with what Rick said is that this is one thing that a lot of individual scientists, academics, researchers should do; find individual interesting stories and so forth. But then they are going to need a common resource, a common database, to compare it to, and understand the general relevance. And I think this is the dream here, this is something that could be provided that one individual who finds, a scientist who finds one big effect, how relevant is it in the general population, and they don't have to create that over and over again.

>> ERIC LANDER: I'm going to jump to Susan because I know we have limited time and another session to go. Susan.

>> SUSAN GRAHAM: So I had two questions. And the first one was the same one that Craig asked about the nature of the collection you're doing. But it seems to me there are also ethical issues related to this whole project. I love this project. You said you're thinking about including children. For perfectly understandable reasons. But children don't give their own informed consent. Their parents give it. And there's certainly a possibility that when those children reach maturity, they take their marbles and go home. They don't want to participate. So my question about that is how useful would it be to have included them for up to 20 years. 21 years, 18 years, whatever it is, if you then lose them. And the other side -- the other part of the ethical issue, which is not original with me, is the fact that you're likely to discover in your preclinical work the strong possibility of disease for which we don't have treatment, and my question is, is that part of this project to deal with these ethical issues.

>> RICHARD LIFTON: Thank you, I think these are both very important questions. I'll make the first point that one of the goals that I think we can articulate in this project is actually quite analogous to genomics. If I want to interpret my own genome, the best way to do that is in the context of as many other genomes as I can get data for. The same I think is clearly going to be true for clinical medicine. And we currently are in a mode where we're somewhat obsessed on the privacy side, which I think there are very good reasons to be concerned with privacy. But if we can get to a point where we recognize that the best way to interpret my own health care data is in the context of a million other people's health care data, I think the benefits that will come from that are very important. And figuring out how to balance the important privacy

issues versus the public goods issue is something that I think this project will enable us to both articulate, explore, and demonstrate the utility there of. On the pediatric side, I think it's a very important element. And it's certainly possible that - and one of the goals of this project is to have the ability -- certainly anyone can opt out of the project at any time. And children obviously will have -- will be particularly sensitive to this issue. And it's an open question as to how long we envision the project continuing. As to what the contribution will be. And how much of a signal can we get early in life. For example, lead exposure in the first five years of life, that may have profound implications in adulthood. But if we never measure it in the critical period for development, we may never have the ability to understand what happens later in life. So clearly complicated and complex issues. A lot of dimensions to consider.

>> ERIC LANDER: Great. Jim Gates you had your flag up, but signaling your question was similar. Did that fully cover your question? Excellent. Well we have a moment or two but we'll need to end in a bit. I wanted to press you guys on the difference between the million person cohort and the cancer effort. Because right now the million person cohort is an extremely large effort that's going to go over the course of -- well it's going to have to be at least a decade and probably two to really fulfill the promise that you're talking about. The cancer component right now is a more limited component. And I'm curious if there are discussions that are going on you know as part of the NIH's thinking broadly, NIH including NCI. As well as the scope of the cancer component might be profitably broadened to be able to -- the vision -- hit the vision that Todd was describing. I don't know if Rick or Todd or George who I think also would have opinions on this want to comment.

>>TODD GOLUB: I'm not in a position to speak for NCI but for the same reasons Rick articulated, the interpretation of a patient's cancer genome is best done in the context of many patient's cancer genomes. So the faster we can accumulate a large collection of such genomes and relate them to clinical response and have those data analyzable together, the faster we will make progress. So personally I think we are being a little too timid in the pace at which we're generating and aggregating these data, and then on the cancer side we would benefit from moving more boldly.

>> RICHARD LIFTON: I do think it's worth noting that the reason the two projects seem so different is because we're so far advanced in cancer compared to every other disease that we're thinking about, except for individual mendelian single gene traits, and one of the reasons is cancer is one of the few diseases where we rarely get the disease tissue and know we're

actually looking at the disease tissue itself. When we have patients with diabetes, we don't do muscle or pancreatic biopsies we don't get the tissue that we think is driving the disease so cancer has been a spectacular example of when you measure the right things in the right tissues, you learn about disease causation, and I think this is really critical in how we shape our thinking going forward.

>> ERIC LANDER: You're saying we get tissues but we're not all pulling this together is really a large enough view of the whole thing. I wondered, George, do you have any thoughts on this? I don't know what Regeneron is doing with regard to cancer here.

>> GEORGE YANCOPOULOS: Yeah, we are separately also doing a cancer type of an effort. As you might imagine. And I do think that these things work together. The more information you have, you can compare each individual to the broader population and learn a lot. Simply you see a mutation, you don't really know if it's normally seen in the population and what its implications are for cancer in the normal population unless you have that database. So I'm agreeing with what Rick and Todd said is that peoples' information is best interpreted in the setting of millions of other peoples information. And that's why one need this as a resource. I also want to echo Todd's comment about being too timid or too slow. The world is moving very, very quickly here. And unless the NIH and the President's effort really get moving, it's going to be obsolete before it gets off the ground.

>> ERIC LANDER: Well, on that note, that's good. (Chuckles). It's great to know that in January we proposed -- the Administration proposed a visionary initiative. And that now in May George is saying unless it gets moving even faster, it's going to fall behind which I think is very much the nature of the field. I think that's why this initiative was launched because there was a sense that there was a tremendous amount of steam behind this, and I think as the questions that you all are working through get answered, it's going to be able to move it in an accelerating pace. I want to thank Jo Handlesman and Tania Simoncelli for the work they did in helping structure the ideas of the Precision Medicine Initiative within the OSTP. I want to thank this panel who are all -- I don't think we could have gotten a more experienced and better positioned panel to tell us about the state of the thinking in precision medicine across the Administration, the academic world, and industry. So thank you very much. (Applause).

## Reimagining Capitalism: Business & the Big Problems

>> WILLIAM PRESS: Welcome back, everybody, to this session, and it's my pleasure to introduce Rebecca Henderson to you. PCAST, you have Rebecca's bio in your folder so I won't go over that, other than to say that she is one of only 24 professors at Harvard who have the title University Professor. She's an economist by training and has worked in a number of very, very interesting areas. To give a little bit of framing for why she's here today, maybe the way to say it is as I look back at the several dozen by now reports that this PCAST has produced over the last six years, you see certain recurring mantras. Some are perhaps to this audience predictable. It's not unusual for PCAST to call for more research in an area that we're looking at. Some might be a little less predictable. I think we very often have looked at areas and seen a need for a more integrated systems approach to problem solving, and then some that some people might find surprising but I think a frequently recurring mantra in PCAST studies is to call for public-private partnerships, PPPs. This is a world in which the private sector supports twice as much R&D as the public sector does. We live in an intensely capitalist society and age, and, really, the big problems facing us, especially with technology elements, for going to find solutions, they have to be solutions that it not only involve the private sector but involve the private sector in a big way. So we turn to Rebecca Henderson because this is precisely one of her fields of expertise, and she's going to talk to us today about "Reimagining Capitalism: Business & the Big Problems". Rebecca, please.

>> REBECCA HENDERSON: Bill, thank you very much. It's an honor and a pleasure to be here—my thanks to the members of the committee for inviting me to be here. As Bill mentioned, I'm here to talk about a research and teaching project at Harvard called "Reimagining Capitalism: Business & the Big Problems". I'd like to stress that I'm not going to be talking merely about my own work, but also about research and teaching that's ongoing among a broader group of faculty at Harvard and at other major institutions, but they are not implicated in what I'm about to say. I'll talk very much about my own cut on these issues. Let me begin for those of you who are going to leap up and rush out halfway through my presentation by giving you the bottom line, which is this is a project about whether, and to what degree, the private sector can contribute to the solutions of the large public goods problems of our time, the big problems, and to give you a sense of what I mean, some of the big problems we're focusing on include environmental degradation, particularly the problem of climate change, inequality, particularly the problem of inadequate access to economic opportunity and problems of education, problems of infrastructure, particularly spending on R&D, and problems of open and accessible institutions more broadly, and I'll talk more about that as I go on. I came to this problem

because I spent 20 years studying innovation and became deeply interested in the problem of climate change and the evolution of energy, and I could not work out why we did not have some kind of price for carbon. It seemed to me that this was an elegant solution that addressed a wide range of problems and would mobilize the private sector to really generate new technology and new solutions in ways we needed, and I couldn't understand why this seemingly obvious public good was not being addressed, and, so, I became very interested in the intersection between public and private sectors and where these public goods come from. Let me begin by saying that when you talk about public goods, the obvious answer is to look to democratically elected, fully accountable, well-informed government, supported by honest and competent bureaucrats, that if you were trying to solve the problems of environmental degradation, or inequality in education, or infrastructure, and you were czar of the planet, or czar of the U.S., you would say, well, you know, it should be democratic government. That's the way to fix these problems, and let me begin by saying that, of course, I absolutely agree, that without democratically elected, fully accountable representative government and an honest and competent bureaucracy, it's going to be a hugely difficult to solve the large problems that we face. Nonetheless, I'm going to suggest that business may have a role in addressing some of these long-term problems. In doing this, I realize that this is something of a heavy lift. Why might it be a heavy lift? Well, famously, Milton Friedman said, and said for very good reasons, that the social responsibility of business is to increase its profits. There's very deep suspicion, both in the economic profession, and in the business community, about the idea that business might have a responsibility to address some of these large, long timeframe issues of our time. It's, sort of, that's not business's role, and indeed, by suggesting that business should address these issues, you run a couple of major risks. One is that managers will take their eye off the ball, and instead of maximizing returns for their shareholders, they will use the smoke screen of, "Oh, I'm taking care of the big problems", to do all kinds of things that might not be appropriate. Secondly, we might fear that business doesn't have the right kind of information, that if we were to say, turn to business and say, "You deal with environmental degradation, or problems of education.", they might not do it very well, and, lastly, there is a risk, I think, that if we were to say no business has a major role in the solution to these problems, that we would get a cover for crony capitalism, or for too close a relationship between business and Government and run the risk of delegitimizing public debate about some of these centrally important issues. So, I fully realize that suggesting that business could play, should play, would want to play a major role in addressing these issues is not an obvious thing. Nonetheless, I'm going to press on, and we've decide to press on. Let me give you a sense of why that is. Firstly, there are problems we face, most noticeably problems at the global level where multinational corporations, with their scope and reach, arguably have more information and more incentive in addressing some of these problems than some local governments. Secondly, there are states in the world where the local government is not very functional for obvious reasons. I will refrain

from mentioning any particular nation-state by name, but there are nation-states where the local government is not functioning all together in the best long term interests of the population, and in those places, large multinational corporations can often play an extremely positive role. Thirdly, and lastly, I think it's important to remember that the idea that business and government should be completely separate roles, that the only responsibility of business is to maximize profits subject to the constraints of the law, is both historically and geographically a little strange. Government and business are fundamentally joined at the hip in a number of important ways. Business has always been an important political actor. Indeed, the advent of free and fair capitalism, and the openness and possibility that it offers to enormous swaths of the population isn't itself political. If we look at the embrace of capitalism in many developing countries, it is experienced as a move to individual economic and political freedom that's hugely important in providing a counterweight to more traditional sources of economic and political power. So, business is fundamentally a political institution, and to say that business has no role in politics or should never think about politics would seem to me naive. The question is, "How should we think about this relationship, in such a way that it supports the broader good of the entire community, without, in any way, harming the central mission of business?" As I talk about this, I think it's very important to be clear that I'm not for a moment suggesting that business should not focus, and focus hard, on maximizing economic return, or, making money. In the first place, a business that doesn't focus on money, doesn't last for very long. In the second place, when we think about the enormous public welfare that has been created by the dynamic innovative private sector in this country and in others, we must not forget that maintaining the private sector as fully competitive, and as free and fair, must be one of our central objectives. I think I don't need to tell this group that the population of the world has tripled in my father's lifetime and he's still alive, and at the same time, GDP per capita has quintupled. That is amazing. Many factors are responsible, but, arguably, free and fair capitalism is one of the most important institutions invented by humans, and its ability to support the introduction of new technology, to roll it out at scale, and to deploy it in a sustainable way, whereby sustainable I mean it keeps on happening, it's not reliant on philanthropy, is absolutely central. So, in saying that business might have a role to play in supporting the big problems, I'm completely cool with the idea that business's first responsibility is to run an efficient and profitable enterprise. Given that constraint, what can business do? And we might worry, of course, that these big problems are by their very nature public goods. That is, that no individual company has an incentive to go after, say, the problems of environmental degradation, or the problems of education or shortfall, or underinvestment in R&D by the global commons. So how do we think about that? I'm going to suggest that there are three broad classes of approach to this issue. The first issue, which, again, called Bucket One, is what I sometimes call the KKR solution. So, I'm talking about Kolbert, Kravis, and Roberts. I mention KKR because they are not famous as a group of greenie

tree huggers, yet every time they acquire a new company, they put in a team to reduce energy use, and to reduce water—to reduce water use. So, they're going right after problems of environmental—environmental degradation—and they are doing it because they think it makes them a great deal of money. So, I think, in general, there are very good reasons to believe that there are a number of opportunities where private firms can address these larger issues, and make a bunch of money in doing so. At Harvard we have a project called sustainability at scale which is the systematic collection of detailed case studies about large multinational institutions, which have found that addressing these issues is, in fact, highly profitable, and this work, of course, is only a drop in the bucket if you look at some of the work of the major consulting firms including McKenzie, or KPMG, or Price Waterhouse, we have an enormous number of well documented cases where firms turned to either environmental problems or problems of weakness in their local community, and were able to significantly advantage themselves by grappling with these issues. Since this is a room of extraordinarily smart people, you're probably thinking the economist question, namely, "Well, if there are \$20 bills lying on the table, why isn't every major corporation going straight to these problems? How come we even have to talk about it?" And here, I will refer back to my 21 years at MIT as the Eastman Kodak Professor of Management—was, in fact, a coincidence that I was the Eastman Kodak Professor, but it's deeply ironic, because that's what I did for 20 years—I studied the barriers that lead very large corporations to not changing, despite very clear signals they should do so. I have worked with firms in a broad range of industries, including automobiles, pharmaceuticals, and MIT. I worked with Nokia, as Apple started to take a real hold on the mobile phone market. This is difficult. It can be the case that there are significant profit generating opportunities, and large firms do not grasp them. Paying attention, understanding why that is the case, is, in my view, an enormously important issue as we try to move against these large problems. And nearly every major business school in the country has a significant effort on this front and is working with large organizations to develop the business models that will make a difference. You may say, of course, that these movements, while important, and I think they are important, that the adoption of early stage renewable energy, for example, brings these technologies down the learning curve, generates legitimation, creates supports for regulatory policies that would further advance these kinds of technology deployment. So, these kinds of efforts can have very significant effects. When we look at the efforts of a company like, in say, Walmart or IBM, in demand reduction and renewable technology, these are important players in the debate. But, you could say, they are clearly not enough. We need much more. And we need to go much faster. We haven't touched the really hard public goods problems. So, let me introduce you to what I'm going to call Bucket Two. Bucket Two are projects that don't have an easy take it to the bank business case. So, changing out the light bulbs for example, that's an easy, take it to the bank business case. Unilever's move into sustainable tea, as an example, was not. Unilever decided some years ago to take their entire tea production and move it to full sustainability.

That is to reduce its energy usage, its pesticide production, to move its workers to livable wage, and to really try to transform the tea business. I've had the opportunity to see the business case that they put together for that, and again, I'm not telling you anything they would not feel happy sharing with you. That business case was at the edge—not negative, but not overwhelmingly positive. Now, of course businesses take risks and make investments like this all the time. When we think about major acquisitions or the decision to kick off a major new product development project, when you look at the business case, I mean, often the numbers add up. But you know, I've been studying this for 30 years. You give me a project, I can get you a positive MPV at root these are risky projects that you have to decide you want to do for long-term strategic reasons. I think there's a very important class of projects in this bucket that make a huge difference against these long-term public goods problems. Unilever's project, in itself, shifted the production, or is shifting the production of \$3 billion worth of tea, that's nearly 3 billion euro of tea. That's approximately 30% of all of the branded tea produced, and Unilever's program led to the adoption by every other major branded tea producer of the same approach. So, they succeeded in shifting the entire tea business. Unilever, which is a leader in this area, but by no means not the only one—a number of the other consumer goods companies are pushing in this front, are working on sustainable palm oil, on a variety of agricultural inputs. If we look at firms like Nike or Hewlett Packard that are working in textiles, and in information technology, respectively, to try and raise the safety standards and treatment of workers throughout their supply chain, these are examples of firms that are using their own needs, so there is a compelling business case, to try and persuade everyone else in their industry to move with them. If you look at what's happening in the extractive industry, in mining in minerals, these are firms that understand, yes, these are public goods problems, but if we can move as an industry, or as a region, we would all be better off if we made progress, and the difficulty is reaching that cooperative equilibrium. The risk is if we all just focus on making money for ourselves right now, we get stuck in what as an economist I might call a defect equilibrium, and we would be much better off if we all addressed these public goods problems. If you look at what's happening in a number of cities across the U.S., I'll talk a little bit about Minneapolis because I've had the pleasure of doing a little bit of work there, the CEOs in that city are working hand and glove with government to really focus attention on early childhood education, and really try and make a difference in that city. So, Bucket Two is all about taking a chance, about acting on your deeply held values, that is your personal beliefs that addressing these common problems is not only the right thing to do, but will improve the functioning of the entire economic system. And the—laying the economic model on top of one might call the deeply held moral case for action, in our experience, generates enormous degrees of commitment and creativity. Indeed, one of the focuses of our research is the effect of what we might call a pro social orientation on engagement and productivity. There's a lot been written saying that yes, it makes a big difference. We're trying to put in place solid experimental design

to show that yes, when you raise peoples' wages, when you treat them differently, when you make it possible to participate in the economic system, effectively, when you announce that we're going to make a difference against these large problems and you do so at scale, you generate a very significant move within the workforce. One concrete piece of evidence on that might be the identity of the third most desirable employer in the world. You probably know that Google and Apple are the No. 1 and 2 most desirable firms to work for in the world. You probably did not know that Unilever was the third, and Unilever makes deodorant and ice cream. Those are great products, but they are not sexy in the way that Google and Apple is. So, there's enormous excitement and pressure within the workforce on the adoption of pro-social. I only have a minute, Mr. Chairman. So, let me wrap by talking a little bit about my third bucket. Bucket Three would be those actions which it might be profitable to do, but which we should refrain from doing. This is a very large topic, but let me say that I believe there's a good case to be made that business has a deep responsibility for sustaining the institutions of free and fair capitalism. That business involvement that either distorts the prices in the marketplace, or distorts possibilities for entry or exit, is morally wrong in the terms of capitalism itself. Capitalism is not a value-free system. It is a commitment to prosperity, freedom, and innovation, across the board, and a move away from free and fair capitalism puts those moral commitments at risk. I think it's very important that we start talking about actions that business can refrain from doing that betray those moral commitments. In closing, let me say that, of course, private sector action on all these fronts is not enough to address the big problems of our time, that what we need is a rejuvenated body politic, that focuses together on public problems of public action with longer timeframes and common benefits, but that's a heavy lift in every nation across the world, given the multiple pressures we face but a private sector that was deeply committed to these actions that acted on them at scale, consistently, across industries and geographies, would make a very significant difference, and is an important part of the puzzle. Thank you very much. (Applause).

>> WILLIAM PRESS: Let's see, PCAST members put your flags up, and I see Wanda is the first.

>>WANDA AUSTIN: Thank you very much for your comments and for your thoughtful perspective on how we can address some of these very, very difficult problems. I think you cited several examples where companies have figured out things that they can do to, you know, improve their personal profile in their public image, which I think is really, really good. We have all heard of computer companies that give kids, freely, computers, so that they learn how to operate their computers and not the other guys, and, you know, there's a potential for a benefit there, and there's nothing wrong with that. I wanted to ask you to share your thoughts

a little bit more about the risks associated with your proposition, i.e., what the company views as good, as an improvement, or an enhancement, and the community may not. So, how do you balance and have that discussion in a private partnership arrangement where the companies see the direct benefit to them, but the community may feel that there's a disadvantage that outweighs the advantage?

>> REBECCA HENDERSON: Thank you for your extraordinarily interesting question that goes right to the heart of the material I'm talking about, and let me give you a concrete example. We teach a case about the Minneapolis—the focus by major CEOs in Minneapolis on early childhood education, and one of the issues that emerges as we teach that case is excuse me, why should a bunch of CEOs be playing such a major role in how Minneapolis addresses childhood education. They have interests which may not be directly aligned with our own interests. They may be doing it to, you know, I'll use the term green wash, or for a bunch of PR and nice photographs of happy kids, and, in fact, their action may serve to subvert real work in childhood education, which needs fundamental attention from many experts, and what do CEOs know about education anyways? So, I mention this by way of completely agreeing with you that this danger is very present and very real. Let me suggest two broad avenues of answer—three broad avenues of answer. The first is that those of us advocating these kinds of actions should never forget this possibility and should talk about it often. The second is that in some cases, I believe the case can be made that the decline of the commons is so acute and the political process so gridlocked that having some portion of the private sector address these issues may play a positive role. So for example, in the Minneapolis case, the CEOs began by hiring people to read all of the research they could. They went after a solution which they believed was consistent with the research, and also with their own beliefs. But they funded scholarships for children that needed to have early childhood education, and they began to get this off the ground. They began to put in place grades for early childhood centers. And you could see in the community really some interest and a lot of take-up, and then they went to the local Government, and they said, “Look, this is not really us. We were trying to catalyze something. We think this is really important.” I may have the statistic incorrect, but I believe in Minneapolis before this effort, less than half of the children were kindergarten ready, and they thought they were seeing very rapid movement and very exciting movement. So, they came to the Government and said, you know, here is the data. So, absolutely, putting on the table that your goal is to catalyze action in the public sector, if you think about if you—one of the things that both Nike and HP have found, for example, in working on conditions in the supply chain is it's hugely important to work with a local Government that in fact one of the most important things they can do is bring their colleagues to obey the local laws. Usually local legislation is very, very good. If you can persuade people to, and create the capability, to enforce it, that's

excellent. So for example, in Mexico, one of the things HP did was support the development of local capability to support local laws. So, that's the second answer—is absolutely work with government. The third is going to sound smushy, but I think it's really important. And here is the third, under what circumstances would you be really nervous about business taking these kinds of actions? Well, you would be really nervous, both if local capability in Government was really low. It turns out in Minneapolis, that's a very high functioning political system. So, your worries are reduced. But the other reason you might be slightly less worried, and get ready, this is going to be very soft, and I'm talking to PCAST, you would be less worried if you really believed that the CEOs of the companies had the interests of the community at heart, and at the margin, were looking and looking hard for actions that really were good for the community, and good for the firm. So, I'm talking about people with very high personal values, with the willingness to talk about those values in public, and the willingness to make concrete commitments consistent with those values. So, it's easy to say, oh, I'm all for the good of the community and I want to do the right thing. Talk is cheap. One of the striking things about these purpose driven companies where that purpose seems to be deeper than talk, is they make short-term commitments that are costly in the service of long-term benefit for the firm and the public good, and, so, one of the reasons I think this program of work is important is when we live in an environment where the discourse can suggest that the only reason managers manage is to maximize returns for shareholders, that any sense of a broader mission which might be increasing prosperity and economic opportunity, which to me is completely consistent with maximizing returns to shareholders, but we've ruled those kinds of languages out of bounds, is a problem, because we, in a way, create and enhance an environment where we are telling people, no, make the money. That's all you need to do, and, so, you can get a cynicism both within business and outside of business that I feel is hugely destructive. No major society, I believe, has flourished without a deep common commitment to the long-term good of that society. That's what moral values are. They are the short-term action that makes you feel good right now might not be skillful. And so let's talk about a focus on the longer term. And let's use all of the resources we have in order to do that. Forgive me that was a long answer to your question but it's so central to this project. I really appreciate it.

>> WILLIAM PRESS: I have Jim Gates next.

>> JAMES GATES: Thank you for the presentation, and the issue of big problems in society is a central one for all societies, and it's also completely clear to us that capitalism is the most effective way that our species has found for generating wealth. So this—there seemed to be a subtext to a number of your comments that capitalism, sort of, at its core has an alignment

with the kind of system of government that we see in our country where freedom is an important component of having a well-functioning market, but in the last decade, or more, we have seen systems arise in the world where, ostensibly, the creation of wealth is under a capitalistic model, but that other forms of managing our society don't follow our democracy, and this has created a model for less developed countries where the value—it used to be, I think, that we thought our system of Government and business were aligned very well for the good of the public, and that this was in fact a selling point of the American model for less developed countries. The last decade, or so, and this is an argument that I think is increasingly more difficult to make, so my question to you is do you really think there's this alignment between free Democratic form of Government and the long-term health of a capitalistic system?

>> REBECCA HENDERSON: As I'm sure you are aware, you are asking one of the deep questions in political science, and I'm going to attempt to answer in three minutes. So, let me do that. So, firstly, yes, I do believe such an alignment exists. Why do I believe this? And one could paraphrase your question as excuse me, what about Singapore and what about China? So, let's think about this for a moment. The deep problem of human organization is that of the allocation of power consistent with the provision of public goods. For hundreds of years we solved this problem through the just king, or the wise ruler. The hope that the just king or the wise ruler who concentrated both economic and political power in their own person would care enough about their people, or would understand that in the long term they would do well to care about the people, but they would operate a more free and open society, and we do indeed have examples of that dating back all the way to Marcus Aurelius. I would suggest that the government of Singapore is an example of as close as you can get to the philosopher king and the idea that one might be able to manage it that way. I would also suggest to you that the record of history is really unequivocal on this respect, that the concentration of political and economic power in a small group has been historically disastrous across multiple societies and multiple periods of time. Now, let me go more recently, and I would point to the situation in Russia as an example of this unfolding. It appears to be the case that when it's a small group controlling all of the resources, the tendency to focus on me and my friends is overwhelmingly strong. Let's take the case of China, and let me preface it by saying that I am not a China expert. That I have deep respect for what the Chinese have accomplished in recent years, and I have no idea what is going to happen, but nonetheless, let me suggest that what the Chinese did was unleash the market system, and we know the market system is amazing. The classic example of what happened in Russia when they moved just a little bit away from the collective system and let people grow on their own plot of land which I believe was like 10% of the total land, and rapidly became 50% of the available food supply. So we know markets were

concrete. The issue is how far do they get you. What China has been doing, how far do markets get you without the other supporting institutions, of what I would call free and fair capitalism and those include free access to information. Free opportunity for people to move into their own profession with full support from the educational system, why are those so critical? Why is it that simply having a market doesn't get you what you need? And I think there are two major answers. The first is—and forgive me I'm going to rag slightly on my economist colleagues here, for years if you read mainstream economics you would think that the price system and just markets would get you everywhere you need to go, but, excuse me, technology and science have been absolutely fundamental in driving prosperity, and what we think—what we know about science and technology is they require very open societies with very high levels of conversation to really support not just venture capital which is amazing. But there's off the wall ideas, the ability to attack incumbent firms who may often be very rich and politically connected, but to attack them and have that be celebrated. That's an institutional effect. That's not just the pricing system, and that's the first reason we think these broader institutions about political participation may be important. The second is that any time there's money, there's the risk of concentration of economic and political power, and now the global economic system generates so much money that the temptation to short circuit the market gets bigger and bigger and bigger, and you're seeing that in China with the accounts of corruption that are coming out, with the preference for people born into a certain class. Everything we know historically is that China will have trouble. They've got to the frontier. Now they need to generate the kind of innovation and dynamism that requires the institutions of capitalism at the same time as the temptation to clamp down is going to get stronger and stronger, and clamping down will kill the goose that laid the golden eggs. So I believe, and I understand it's a belief, that yes, capitalism rightly understood is entirely consistent with Democratic freedoms, and, indeed, if you look at the emergence of democratic freedoms in the West and in the U.S., one of the things you see is small business and the middle class playing a hugely important counterweight to the concentration of power in the old futile and noble hierarchies. So, you know, I teach at a business school. I would believe this, but I think it's something that we need to reclaim and celebrate, because too often capitalism is associated just with the instantaneous maximization of profits. The private sector capitalism is so much more than that, and we need to talk about that and work to make it a reality.

>> WILLIAM PRESS: Thanks and maybe the last question we'll have time for is Mark Gorenberg.

>> MARK GORENBERG: Bill, thank you. Dr. Henderson, thank you very much for your talk and at the highest level I think we're all believers in the idea that companies should have a softer side

and actually give back and not purely be driven by their quarterly profits. One sort of great CEO and philanthropist in San Francisco, Marc Benioff, started a program called the 1-1-1 Foundation, and this is where 1% of people's time, 1% of their technology, and 1% of their profits, went back to the community and philanthropies, and that's led to quite a bit big outcome now, I think \$185 million in profits alone back to the community. The reason why I bring it up, though, and a number of companies by the way have copied this, the reason why I bring it up, though, is it's not one at the beginning that was coordinated and negotiated with government. It was one where the company did it primarily to be a better company to attract employees to want to work there, and the community has been a huge beneficiary of that. So that's been done within the realm of pure capitalism, I think, without the government interceding, although the government has become a partner over time. How do you feel about models like that, and is it really required for the government to negotiate at the beginning? Or is this something you think voluntarily could be successful?

>> REBECCA HENDERSON: In a minute. Okay, no problem. I must say, when I teach this material I teach 28 one and a half hour sessions, and this is like complicated material, so quick answer. Firstly, I think the kind of initiatives launched by Mr. Benioff can play a very important role. They focus attention on the value of these public goods, and the value of these public goods to companies. Secondly, I do not think they are nearly enough. I think that we need to think about ways to incentivize and support companies that act in this way through government action. The most obvious might be through the adoption of metrics in the financial sector. So, if we could think about how to distinguish, concretely, and quantitatively, those companies that are moving against these issues from those companies that did not, embed them in the way we think about evaluating companies, and see if capital is interested in moving against them, that could be hugely important, and could make a very big difference. If, in fact, behaving this well leads to higher profits, let's look at the metrics, let's make it general. Secondly, of course, these are public goods problems. These are structural problems. They cannot be addressed without government involvement. One of my beliefs is that if we start to move down this road, this will become increasingly clear, and the kind of actions you saw HP taking in Mexico, where they were happy to fund the development of local Government capability, because having those laws enforced in smart and thoughtful ways was central to the health of the entire system, will become much more the norm. One of my colleagues, Elizabeth Canter, ran a conference on infrastructure that I had the great good fortune to attend a room full of CEOs from companies across the U.S. and they talked about everything that needed to happen in infrastructure and at the end she said, "You guys have just ragged on business, and ragged on government, and ragged on regulation. How many of you are actively lobbying for better transparent regulations in ways that benefit the whole community? How many of you are part of this conversation in a

constructive way? And it was an interesting moment in the room, and so, it seems to me that part of this agenda is business thinking constructively about what they can do to support regulation that support these public goods. Thank you very much.

>> WILLIAM PRESS: Thank you. Why do we all thank Dr. Henderson. (Applause).

>> WILLIAM PRESS: And I turn the session now back to Eric.

>> ERIC LANDER: Who will turn it back to John.

>> JOHN HOLDREN: Thank you, before we close this session, I just want to mark one arrival and one departure. We are very happy in OSTP to have lured Professor Ed Felten from Princeton, a world renowned expert in cyber security and privacy as well as other aspects of computer science and I.T., to join OSTP as a deputy Chief Technology Officer. Ed is sitting down on the right, and we have to bid a reluctant farewell to Viktoria Gisladdottir who has been the PCAST intern, and is sitting over by the door. She is returning to complete her PhD in mechanical engineering to UC San Diego. So, welcome to Ed, and farewell to Viktoria, and we thank all of you who have taken part in this meeting, either as active participants, or as witnesses, both in the room, and on the web, and we look forward to seeing you at the next PCAST meeting. (Applause)