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WILLIAM So I'm going to combine these two pieces together because they're obviously have a lot of
BONVILLIAN: overlap.

AUDIENCE: Would you mind talking about innovation?

WILLIAM Isn't that the course? Wait a minute.

BONVILLIAN:

AUDIENCE: Good point. So Berger and the Jonas Nahm reading talked about how learning takes place at all points in the design cycle and how we're not really linking games. Well, I know you're about to talk about this now, but--

WILLIAM I promise.

BONVILLIAN:

AUDIENCE: --we talked about how basically the United States didn't concede with innovation as existing in manufacturing. Will you hit on that now?

WILLIAM Yeah. I mean I can do that now, and it's not really in either of these readings. Briefly in the
BONVILLIAN: decline of US manufacturing reading. We'll talk about this in depth next week when we dive into the origins of the US innovation system where it came from. Where did the R&D agencies come from? But in essence, when the US is constructing, its innovation system in the course of World War II and the immediate aftermath. And we'll read Vannevar Bush and talk about him next week.

Before the Second World War, the US wasn't all that strong a science power. There were countries like Germany and Britain that were considerably further ahead by general world view in science capability than the US. And Vannevar Bush worked hard during World War II to build up that early stage research capability and then link it to more applied stations of the course of the war.

At the end of the war, he has a choice. What do we save? And he decides as the war is

winding down-- and we'll talk about this next week. --he decides to save that early stage research capability because that was what the problem was. The United States was king of manufacturing. Manufacturing production capability in the United States dwarfed every other country, including our two major postwar or pre-war competitors, Germany and Japan. We just had much bigger production capability.

We had developed mass production we would read. No one else had figured out, in part because we could sell into a continent size economy. We created the first continent sized industrial economy, and we could sell into that. So production wasn't the problem. We completely dominated production. It never occurred to anybody in the US that there might come a challenge to US production capability.

Instead the problem Vannevar Bush is trying to solve is building this early stage research capability, which we didn't really have that strong a system prior to the war. So the US innovation system when it gets created in that post-war period-- and we'll go into this next week. --doesn't focus on production because it's not a problem.

In countries like Germany and Japan-- which by the way, we had just bombed their production system. They've got to restore all that. They've got to rebuild that. They develop innovation systems that are focused on production. That's where they focus the innovation systems. Not like the US does. We think R&D is king. Other countries assume this link between research and production and focus on the production stage because it is indeed highly innovative. We just are organizing our economy very differently. We miss that, and the results are painful.

Does that answer more or less? You can keep pushing on that too as we go further. Martin?

AUDIENCE: First, I was going to ask, you spend a lot of time watching each other. How willing are politicians to listen to you or people that are more educated on the matter?

WILLIAM BONVILLIAN: Oh. They're on the phone all the time to me Martin. Believe it, it's unbearable. It's constant. You heard my cell phone going off through the entire class. No. This is only a set of realizations that the political system is starting to come to. And it's been a painful set of lessons.

AUDIENCE: So what's the line period? So politicians are just starting to figure it out. When did you figure, or like people that are better--

**WILLIAM
BONVILLIAN:**

Well, I was lucky enough to hang out in MIT and get educated by people like Suzanne Berger and a series of other terrific MIT folks who began teaching me what had been going on here. So I was a beneficiary of the MIT fire hose. I get to stand in it for a significant period of time. And so my next book will be on manufacturing. So a lot of the snippets that you're seeing here will be carried over into that book which MIT Press is publishing. I mean why it takes a year to process a book even though you submit it online is beyond me. But it will come out around December of this coming year.

But let's go back into our story. I should add one more thing, Martin. Donald Trump just won the election on these issues. This is a lesson that is now being learned by the political system. Are they going to come to the right conclusions about what to do about the right policies? I don't know. But this is now embedded into the political learning lessons.

So hollowing out. I argue that's what the story has been on employment, and manufacturing was down almost a third in the decade of the 2000s. It fell to 11.5 or 11.8 I guess, and it's now back at 12.3, but that's not that far back. It was 17 before all this started, millions of jobs. Investment. Manufacturing fixed capital investment declined in the 2000s for the first time when we started collecting the data, an actual decline in that time period.

So in part, as a result, output is down. If you're not investing in capital planning equipment, what's going to happen to output? So output was down in, depending on how he counts, either 15 or 16 of the manufacturing sectors that the government measures. And then, if output is lower than assumed, then productivity is going to be lower than assumed-- as we discussed before. So this is the documentation of the very sharp decline in manufacturing employment. In that time period, from here to here. So you see what happened.

This is national R&D intensity. Right? So this is all related to your investments in innovation, although the lag time is significant. So here's the R&D intensity of the US economy. GDP expenditures as a percentage of-- gross R&D expenditures as a percentage of GDP.

This is-- we saw this earlier-- this is the trade balance for high technology goods versus all manufactured products. Huge deficit in all manufactured goods in the US. Increasing deficit in advanced technology goods. Are you going to make this up on services?

Well, services have been growing. But look at that growth rate compared to the fall out in the goods balance. Now, this good balance gets better because, in the recession, we're not

producing anything. So, therefore, we're we aren't buying anything. But that's the real number, and we're back to that range again-- in this time period.

So as you can see, even if we're staggeringly successful in services, it's not going to offset the balance in goods.

AUDIENCE: What's that random blip that [INAUDIBLE]

AUDIENCE: That's 9/11.

WILLIAM Yeah, that's 9/11.

BONVILLIAN:

AUDIENCE: Yeah, why did the services increase?

WILLIAM I have no idea. I'd have to look at that. We certainly weren't flying many airplanes that week.

BONVILLIAN:

AUDIENCE: Yeah.

WILLIAM I'll have to take a look. So we'd been assuming, as I said earlier, that we'd been losing manufacturing jobs because of productivity gains. But that just really has not been the story. And this means, then, that we're not just going through a normal business cycle here. There's real structural effects here. Right? And we're not going to get out of this by just coming out of a normal business cycle. In fact, we didn't get out of it by coming out of a normal business cycle.

BONVILLIAN:

These manufacturing jobs are not coming back-- they're gone. Therefore, you've got not a business cycle problem, but a structural problem. This is percentage loss in manufacturing jobs between 2000 and 2010, by state. So the green states lost 30% to 40% of their manufacturing jobs. The purple states lost over 40% of their manufacturing jobs. So think of what was going on in textiles and furniture in North Carolina, or the auto sector in Michigan. But the overall picture-- it's not a pretty picture, nationwide.

So we've had, kind of, an American Brexit here, with a lot of social disruption. So the manufacturing decline tended to create societal decline. So when we lost a third of the manufacturing jobs-- historically, manufacturing was an important middle-class pathway for, particularly, high school educated males.

But full employment-- full-year employment for men with high school, but not college, degrees

went from 76% in 1990 down to 68% in 2013. In other words, we may have unemployment now back to 4.9%, which is terrific news. But we don't count this structural decline of people who, in effect, have left the workforce-- which is still there, as a deep structural problem. So the share of men that did not work at all in that time period-- with that level of education-- went from 11% in 1990 to 18% in 2013, which is a pretty staggering number.

Most importantly, you can't measure this stuff by average income. You've got to measure it by median income because the gains of the upper middle class disguise the decline in the other income quintiles. So you've got to look at median income.

Median income of men, with no high school diploma, fell 20% between 1990 and 2013. And men with a high school diploma, or some college, fell 13%. So there's a growing income split between college and non-college educated-- and a major accompanying rise in income inequality.

So David Otter's picture of this is of a barbell. And one of the bells-- and Beth could tell us this-- but one of the bells is growing. That's this upper middle class bell. And that community is doing quite well. But then there's a thinned out middle. And a lot of that thinned out middle has been push towards the other bell, which is a growing lower end, lower paid services sector. So we're thinning out the middle and, therefore, creating this big economic inequality problem.

I mean, this is in a country that created a democracy that delivered staggering social mobility to its population. Staggering, unprecedented in the world, right? And we're now bringing that to a close. We're shutting that down. What are we doing? And the social consequences of this are actually profound.

So the election just told us-- completely disrupted the Republican Party, and caused huge disruption across the board of all parties. It's an incredible message, that just got delivered here in the United States. In wrestling with this and trying to understand and figure out what to do about it-- I think it's pretty fundamental to the future of the democracy. We will avoid this problem at our peril.

So we've got a loss to middle income ranks, growing social inequality, and a whole post-industrial backlash that's going on here. And the question is, can this idea of advanced manufacturing, in some way, speak to some of this? So manufacturing remains a big sector. It's \$1.7 trillion of a \$15 trillion US economy and employs 12 million in a workforce of 150 million. It tends to dominate the innovation system. So-- approaching 64% of scientists and

engineers are employed by industrial companies.

AUDIENCE: I thought that back-- you had shown us before, said that manufacturing had like two thirds of. What was it two thirds of? The two thirds of--

WILLIAM BONVILLIAN: No, it's not it's-- it's of fortune-- of Standard and Poor's 500 companies. It's their-- in other words-- the companies that make the money. What portion of their money comes from production versus services, right. And these are the companies that are delivering for the economy, frankly. These are the big companies that tend to dominate a lot of employment.

AUDIENCE: So why is there this big discrepancy and why isn't anyone [INAUDIBLE] I mean, if it's only above 10% of the poorer economy?

WILLIAM BONVILLIAN: Because manufacturing is pulling above its weight in what it delivers. So the currency of international trade, really, is about complex high value goods. It's not about services. That's what this story is. That's what this graph on services-- trade surplus versus goods deficit-- is all about. The returns are really coming, predominantly worldwide, from complex high value goods.

So if you start to reduce your capability-- and remember, the United States is still, by far, the second largest manufacturing entity in the world-- there's still a lot going on here. 80% of US exports are in this high value, goods area. Yet, we're running, in 2012, a \$700 billion deficit in goods. We talked about this a bit. At the end of-- or, began to talk about it. At the end of World War II, when the US dominated the world production system, frankly, we were able to get a full spectrum of gains.

So we innovated here, and we produced here, and we got the full benefit of gains across the entire spectrum. And then, as Suzanne Burger's book showed us last week, we figured out how to distribute production. How to separate production and design-- largely, IT enabled and driven by the financial services models-- we figured out how to separate those two. And we increasingly began to try to innovate here and produce there. That means that you're losing a good part of the full spectrum of gains.

Now, the risk here is that if innovation is, in fact, related to production-- particularly, initial production of a new technology-- If that's a very creative, innovative stage, and you're shifting that-- then producing there is going to mean that you're going to innovate there. Right? Because the production has got to be located close to the innovation-- for lots of kinds of

goods. Not all goods, but for lots of kinds of goods. So the risk we're running, and that we're starting to see signs of, is that producing there may lead to innovating there as well.

So, Matthew, in the example you were giving before about your-- was it you who raised the hard technology startup?

AUDIENCE: Yeah.

WILLIAM BONVILLIAN: Yeah. Your friends moving to Shenzhen to do the rapid scale up, which Shenzhen is extremely good at-- logical move. But they're locating in a significant part of their innovation capability there, now. And my guess is that when it comes time for them to do the next round of incremental advances on their good, they're going to innovate there. So in a nutshell, that's what's going on now on a larger scale. So that affects the spectrum of gain that gets distributed in this country.

So let's suppose that the US wanted to go back to production leadership. It's not going to have production leadership in everything, by any means. But let's say there were some areas that we could have production leadership on. What would we need to think about? What will we need to understand?

So the essential argument that the Production in the Innovation Economy study and that the Advanced Manufacturing Partnership study came to was that, historically, shifts in manufacturing advantage have stemmed from the introduction of a combination of technology advances, accompanying process advances, and new business and organizational models.

If you can combine these, you can get a production advance. So we were talking last week about the remarkable quality production model that Japan launched in the 70s and 80s-- on the world. That's what they did. They introduced new technology advances, process, and new business models in combination. It was a remarkable story. And they captured a significant portion of world production in areas like, autos and consumer electronics.

When the US was developing its mass production model, we did the same, and, exactly, the same thing occurred-- technology process business model. So are there new technology advances that scientists and engineers tell us may be at hand-- that we could use to develop production innovation?

So how come the US has such trouble competing in manufacturing? There's a bunch of macro factors, and I do not want to underestimate those. So the US tends to have a very high valued

dollar. Countries like Japan and China work on maintaining a lower currency valuation. So they get a competitive advantage every time they sell a good. Right? That's not to be underestimated.

The tax system in the US tends to actually, somewhat, favor components that are imported rather than components produced here. So part of what the president is attempting to address in this whole debate over border adjustability, is that tax problem. We also have a tax system that favors debt over equity, which tends to make our companies much more fragile. Equity is much more assured in longer term. Debt has to be accounted for and managed and can hit you in the short term, very quickly. It makes our companies more fragile.

So there's lots of macro factors here. But what's new in this story is an attempt to put an innovation story on the table. Could we bring our still-strong innovation system to bear, really, for the first time, frankly-- on some of these production challenges?

Now, we did have an episode, we talked about briefly, with Sumatech, in the 1980s and early 90s. A challenge to semiconductor production led by Canada and Nissan in-- Canada Nikon in Japan. And the US organized what was, in effect, a manufacturing institute and got its production process down-- and went to creating much higher quality goods that could meet and match their global competitors. So that's the one kind of episode where we've tried to do something in the past. But there's been nothing like that since the early 90s.

But the point that the engineers and scientists seem to be telling us is that there looks like there's a bunch of technology advances, around which, we could construct new production paradigms. Like, what Japan did on quality. Like, what the US did on mass production.

And there's lots of lists of these, and we'll talk some more in a minute about some of them. But maybe, we could do network centric production. You know, a mix of advanced IT RFID sensors, make every stage of the production process smart. From the origin of the resource, through the entire lifecycle of the good. And it talks to you and informs you about what's happening and what's going wrong and how to fix it.

And bring in the mix of advanced robotics, which is really co-botics, at this point.

Supercomputing modeling simulation-- all that stuff. Could that bear on a whole new way of doing, kind of, smart manufacturing-- we could call it. There are lots of advances in materials-- it's breathtaking.

We're thinking about a materials genome, including, with a lot of leadership here at MIT-- where we would be able to, precisely, design a material to fit the exact need of a product-- from a molecular structural point of view. That's absolutely breathtaking. Nano fabrication-- all kinds of possibilities emerging here. Something called mass customization-- we may be approaching the ability to produce small lots of goods at the same price as high volume production.

So that changes everything, right? That means, you can do local production-- like you do local food? You can do highly localized production for highly customized designs. We would get to participate in the design process rather than being a customer at arm's length.

The history of manufacturing has been ever more relentless, to scale up. This could completely change the story to scale down-- and much more, in effect, personalized production technologies. So things like 3D printing and computer driven technologies and equipment, combined with a series of other steps, might enable production of small lots at the same cost as production of large lots. That would be remarkable. Just-- all kinds of gains to come from distribution efficiencies. All kinds of gains to come from energy efficiency.

So there's a series of these potential new paradigms that could be there, that could give the US an innovation advantage and better be able to compete. In effect, we'd be competing on innovation in historic strength, rather than competing in areas that are much more outside our control. So what would you do?

Manufacturing is sectoral. Aerospace is really different than making cars-- which is really different than electronics. But could you launch technology paradigms that create benefits across a series of these historic sectors? Well, let's run it.

So across the top are a matrix of potential new paradigms-- or, series of sectors-- and on the left are new production paradigms. How do they match? Do they serve a lot of sectors? It looks like they do. So then you're getting a multiplier out of your investment, in a new production paradigm.

Step 3-- as we talked earlier, it's no longer manufacturing or services. The 21st century firm is probably going to combine the two to create tradable goods with tradable services. Step 4, we need to understand what our competitor nations are doing. We just talked about China. It's really important to understand the advances they've come up with-- production-- there's a lot to learn.

There's deep workforce issues, and there's some lessons from the way Germany does things. But that's not going to fit here too well. Maybe, there are other models we can utilize. There is this deep financing problem. The financial services sector has gone to international modeling, and the end of face to face banking has really affected small and midsize manufacturers-- as we talked about earlier.

The focus on core competency, and driving firms to go asset light, has had a profound effect on industrial strength, overall. These are big challenges. A lot of what's happened in manufacturing has been driven by financial services models. There's no getting around that. It's hard to change these. But, maybe, we could think about ways of substituting on the venture capital problem we're having now-- which is, that it's, largely, not available to hard technologies.

So that's kind of the story on these two readings. I'll just close with an image for you on how to understand employment in manufacturing. So think about an hourglass. And at the top of the hourglass, here's the production moment. And there's about 12 million workers there. Flowing into that production moment are all the resources, suppliers, component makers, and, as we talked about earlier, a large part of the R&D system. That's flowing in to that production moment.

And then flowing out of the production moment-- whole distribution system, lots of services, lots of sales, lifecycle of the product, repair-- huge sectors. The top and the bottom up the hourglass are much bigger than that production moment. And, through the hourglass, our value chains of firms-- firms that are linked to each other. And when you snap the value chain, by ending production, you're messing up those value chains. That's what we did in 2007 and 2008. We did it for the entire decade but, particularly at that time period.

And it's very hard to reestablish these value chains. So the effects of manufacturing employment are not simply here, they're throughout the whole system. And look, on the other side of the coin, the jobs in manufacturing are not necessarily going to be here. They're going to be in the system because the system is so interdependent.

So manufacturing is well understood to be the strongest jobs multiplier. In other words, a manufacturing job leads to more jobs because of these interrelated value chains, throughout the whole system. Service is a much, much lower job multiplier.

So if you affect manufacturing, you're affecting job multiplication throughout your whole economy. And the reality is that the jobs in manufacturing need to be seen as part of this system, not, simply, at the production environment. And we've been affecting the whole system.

Now if you substitute an imported good for a US produced good, then you can re-establish a good part of the distribution system repair and so forth. But you don't re-establish the top end. And you often have a different value chain arranged for that.

So I tried to come up with an image that, kind of, explained what's been going on here. But I think that's probably the best one I've been able to cook up, in terms of what the effects have been. And we've been living the effects of snapping those value chains and firms by snapping production.

AUDIENCE: So the general idea I'm getting, is that we basically need to develop new tech that no one else is prone to be able to manufacture. And we need to be able to manufacture it before they can.

WILLIAM BONVILLIAN: And that's what we're going to debate. That's where we're going to go to next. So Steph do you want to lead us off in some Q&A? It's all yours. I know you're ready for this. You've been gunning for this one.

AUDIENCE: I think we've all been gunning for this one, for some time.

WILLIAM BONVILLIAN: And you can come gunning after me, too, if you want to-- it's fine.

AUDIENCE: So first of all, I just wanted say that it is a nice privilege to be in this room, to hear all of your resolve. You're incredibly intelligent. And as someone who comes from a low income immigrant background, to be a part of the conversation-- to sit at the table is an immense privilege and an incredible rarity.

And so we've talked about those really difficult cliches-- I hope that we remember our experiences influence who we are-- and how the family that we belong to and peers that we have and how technology [INAUDIBLE] shift our lives-- in addition to the ways in which education, our nation, and the conventional wisdoms of our culture have really shaped our understandings of power and influence of English clarity-- with relation to how difficult the next decade is going to be for Americans and for people around the world who are going to be

affected by the election. But, remember also, that while these factors are influencing us, we have the ability to influence these factors back. I just wanted to take a second to remember that.

The second thing that I wanted to ensure to address was something that I spoke with Bill about last week-- it was in the context of Japan-- and that's, the role of mental health in the workforce. And Japan has one of the highest rates of suicide amongst labor workforce. And that has only been increasing over the last two decades.

And in particular, because of the strenuous hours that workers are forced to attain-- in addition to the enormous pressures to work for very influential firms. In addition to the fact that most of them say, I want a firm, their whole life-- only switching if they're immensely uncomfortable and get a better position. Which, is obviously a rarity in our society.

And to that point, the flip side of the story is that in the United States, there's also been a sharp increase in suicide amongst white population. In particular, white rural peoples. And there is a study that came out last year in *The Washington Post*, where in February 2016-- only a couple of months before the election-- they made a very good point about talking about how rural women had an increase in suicide rates from 47% in the last 10 years-- more than urban women.

So rural women are disproportionately experiencing the impacts of the loss of manufacturing capabilities and the loss of [INAUDIBLE] dynamism in production because they are the ones who have to, ultimately, bear the brunt of the home economics. And then, in addition to that-- white suicide, generally, has only decreased 1% since 1995. Whereas, suicide rates amongst Hispanics and African-Americans were two of the groups surveyed and have decreased over 47% in the last 20 years.

So the fact is, that in addition to that-- in the last decade, there's actually been an increase in white suicide as well. In particular, after 2007, amongst white men. And so white men are now independent of people being targeted for homophobia, transphobia, et cetera. White men, and especially middle aged white men, are the ones who are most at risk of committing suicide-- as a result of the downturn in the American economy.

So the 2007 crisis is a strong correlation with the increase of suicide amongst white males. So consider, these are very real issues that we're dealing with. And I think I was sharing with Bill that one of the difficulties of having this conversation-- I think, in this room, and more across

our homelives and our areas of influence, is that I think it can be very hard to put ourselves in the shoes of the American manufacturer who has lost their job.

It can be hard to understand the implications of what it means to be a person who is now facing a job loss or the extinction of their job opportunities. And, now, here we are talking about the potential for retraining programs and what does that look like. And what opportunity will they have in the next decade and the next generation?

And for myself, a moment where I felt this very intimately was-- maybe, two weeks ago when I was studying for my CS111 p-set that's undertaking learning to code in Python. And I'm doing it because I want to learn more about technology because that's my concentration. And here I am having a panic attack at 10:00 PM on a Saturday night because I'm trying to figure out how to code. And I realize that this is not my livelihood on the line. It's just me trying to learn something new just because I enjoy it.

So I hope that we take the spirit of understanding and compassion in trying to figure out how easily we can negotiate between protecting the communities that matter to us-- as well as maintaining American competitiveness and collaboration on a global level. And, at the same time, remembering the immense difficulties that people in our country are facing. And, at the same time, how difficult it is for the United States because we're in a compromised position-- because so much of our economy has been built on the backs of laborers in developing countries. So human rights exploitation is not something that we directly talk about in this course. But it's certainly something that is relevant. So I hope that as we enter this discussion, we keep all of those factors in mind. Again, approaching this with an open heart and open mind and being to critically assess these very difficult questions that we will have to deal with as emerging leaders in the field. And with that--

WILLIAM

BONVILLIAN:

Steph, let me add something to your powerful points. We've talked in significant part of the effect of manufacturing decline on white males. Those were the data points that I brought to you. But we need to remember here, something that's been going on that's every bit as powerful.

In that post-World War II era-- during World War II and that post-World War II era the African-American community in the south goes to great diaspora and moves north to seek an opportunity to break in the middle class with these industrial jobs. And it's a moment of incredible hope. There's actually a path forward with these well-paid industrial jobs. And that

community enters areas like the auto-sector in significant numbers. And that's going to be the path ahead. And those hopes, in significant part, have now been totally wrecked. And we've got all over the country these shell cities.

Think about Detroit. Think what's happened in Detroit. This is not simply a white, working class problem; this is a much deeper problem in our society that we're now just starting to think about and confront. So I just wanted to add that on top of your picture.

AUDIENCE: [INAUDIBLE] I think there's a lot to be said, I think, for the differentiation or the impact. The other point I would add to that would also be the role of the exploitation of immigrant communities over all areas, in particular that benefit off of the manufacturing sector. For example, so if my family members worked at meat packing plants in Nebraska, others will get production plants in other parts of Nebraska. And my life looks very different than theirs just because I got really lucky and got to go to school in Texas. So I invested in me, got to go to Wellesley and my life is different from theirs.

So as we think about the nuances of the implications on this election, the first question I wanted to start off was actually Luyao was talking about earlier, specifically on this question of the America First framework. You mentioned how far can we see firms as customers who use their investment decisions as votes for different economies and markets. Outsourcing US firms can be seen as a reduced marginal utility of manufacturing investment. So in a world in which we understand America's firms as in investing in other countries, what does this say about their values as in your opinion?

WILLIAM Now, that was a big question. That was big.

BONVILLIAN:

AUDIENCE: [LAUGHS]

WILLIAM In fact the word huge comes to mind.

BONVILLIAN:

AUDIENCE: [LAUGHS]

WILLIAM [LAUGHS]

BONVILLIAN:

AUDIENCE: What does it say about our companies because they value profits?

AUDIENCE: I think it's still a question of what to do to make the firms-- to attract the firms back to the US. I think I'm not-- I've only started to follow US politics after I came here. [INAUDIBLE] Trump would propose how to do this, telling them not to [INAUDIBLE]

WILLIAM BONVILLIAN: Let me just add a statistic, Luyao, to what you're saying. Like weekly job churn in the United States, the number of jobs lost, and acquired, 75,000. Right? Staggering. So if you've got the president on the phone twice a month saving 200 jobs, you haven't done anything. These are systems issues, deeply etched into the system we've got, and those are arguably the issues we need to tackle.

AUDIENCE: I don't know how much you can blame corporations for these decisions in general, at least for larger ones. They're subject to their shareholders, which is, their shareholders will want returns, but if you could get a large group of shareholders that said, we want you to make less money and build in America or we're all going to sell and your company is going to lose all its value, then they would actually change something. But I feel like it's kind of like a grassroots movement that would be necessary, like the idea behind the divestment movement is to kind of encourage that. But even those groups, while they are growing inside are too small to really make a big difference right now. So we'd have to come from like--

AUDIENCE: Another thing too, even if you make all the choices, like the CEO of the company, and you get sued if your stock drops too much. So it's like, yeah, [INAUDIBLE] thinks that he would ultimately [INAUDIBLE].

WILLIAM BONVILLIAN: So thank you. Appealing to corporate goodwill to reduce profits is probably completely unworkable, right? So what are the other-- what other territory can we work in?

AUDIENCE: The other things that you could do-- you give them incentives. So either, for example, manufacturing in China-- make it less attractive. Or make manufacturing more attractive. So in order to make it less attractive, manufacturing in China, you could [INAUDIBLE] like trade tariffs. We don't have any tariffs with China, do we?

WILLIAM BONVILLIAN: Well, both countries are part of the World Trade agreement. So there are modest tariffs remaining. But it turns out to be a much more complicated global system than simply the way tariffs operate.

AUDIENCE: Like one thing is never going to fix this.

WILLIAM Right. And look, the multinationals have to be in all the big markets.

BONVILLIAN:

AUDIENCE: Yeah.

WILLIAM Right? If you're running a multinational that's only, you know, selling into one continent rather
BONVILLIAN: than four or five, you've got a heck of a problem, right? So you're going to need to be where your markets are. So what else can we do?

AUDIENCE: I think going off that idea of getting incentives, I think kind of relaxing maybe tax rates on a lot of corporations, like overseas funds, could be an interesting way to approach it. Like right now, I'm taking a tax class from Michelle Hanlon, and she's really behind the idea that the overseas, the 40% tax rate that would be implied, or sorry, levied on anything that comes back into the US, which could be feeding economic growth, creation of jobs, perhaps fuel more pursuits here in America-- those are just staying stagnant pretty much overseas, because those are tax havens. And that's how they can best maximize the game of not paying so many taxes and still having a lot of reserves for their company to show the profits. But obviously, controversial, and tax policy takes a long time to change.

AUDIENCE: Martin, do you have a comment about tax policy [INAUDIBLE]?

AUDIENCE: [INAUDIBLE]

AUDIENCE: Slightly [INAUDIBLE].

AUDIENCE: Yeah. I was just going to say, it's something that-- OK, as a business person, I feel like it's definitely a political spectrum, the political side that needs to deal with this issue. But also, as somebody who knows history well, I'm very doubtful of politicians that have to get funded every four years or two years by somebody. And I just don't think it's a great system that way, because people have this short term thinking, and then most likely will be somebody with corporate interests or corporate ties, and lobbying will be a effect.

And so that's-- that's the thing that I think is a big issue.

AUDIENCE: But just maybe to clarify a little bit-- so I understood [INAUDIBLE]. Instead of these offshore tax havens, [INAUDIBLE] taxes levied for leaving interest offshore, and you want to bring those assets, and kind of make it more attractive to keep your money and let it be taxed here by relaxing these rates?

AUDIENCE: Mmhm.

AUDIENCE: Interesting.

AUDIENCE: Anybody have any more comments about tax havens?

AUDIENCE: Oh. You could take the other route, and rather than just get rid of the taxes, which like you said, could create a lot of jobs and a lot of wealth, rather than just reduce them, why not just make it so that these tax havens are impossible to use? Which should be illegal, but--

AUDIENCE: Is that politically possible, though?

AUDIENCE: Probably not.

WILLIAM BONVILLIAN: Look. I mean, the new administration is, as I mentioned earlier, pushing hard on border adjustability, which frankly, is the system virtually every other country has. It's going to be really hard politically to get that done. And it's also pushing hard on a new way of treating debt versus equity in the tax system. Those two pieces alone could be actually fairly significant if they're able to do them. You know, we'll see. But Steph, go back to some of the questions that you've got ready-- the arsenal that you've got waiting for us.

AUDIENCE: She's like, all right, let's go.

[LAUGHTER]

AUDIENCE: [INAUDIBLE] actually [INAUDIBLE]. So I thought that this was a-- this one's from Beth. And I thought that this was a really important question, in particular because of the group of people that's assembled here. She asks, manufacturing is no longer seen as a cool or innovative job by many students, especially at MIT. As startups in Silicon Valley attract talent, how can these perceptions be altered?

AUDIENCE: This is really funny. I was just talking with a friend of mine from another school about this. We were watching *Saturday Night Live*, I think, and a GE commercial came on. And we commented how literally, from the last few years, all of the GE commercials have not been about, buy our product. They've been, please come work for us. So they had this slew of them that were like-- I don't know if you guys have seen them, but there was like, the young kid who goes to his parents and says, I got a job at GE, or to his friend, I got a job at GE. I'm gonna be writing code. The jig is the world. And his parents are struggling to see that as an interesting

thing, because in their minds, GE is the big hammer. They build the big machinery, and it's very mechanical, old manufacturing style to them.

And then there was a GE commercial that just came out recently, the [INAUDIBLE] one, that was talking about how they have this new initiative to encourage, to get a higher number of women in technical jobs by 2020, I think. But just-- yeah, I think it's definitely a very pervasive attitude. And maybe some of these older giants are starting to take note of that as they're looking at their workforce age dwindling.

AUDIENCE: If I can ask you a followup-- I know in the reading, it talked about the importance of working in the manufacturing plant for engineers to really get a sense innovation capacity in production. Could you talk a little bit about how you might feel if you had to go to a production plant to start off your career?

AUDIENCE: Yeah. No, I agree with previous sentiments that other people have expressed regarding that. I think it's very important for engineers, or people who work strictly at design or maybe, you know, with a CAD program for the majority of their career to see how things work on the ground floor. I had an internship last summer where-- I wasn't working on this project. But the person who was paired with me on the same project, her entire summer was spent designing a wheel. Not just one wheel-- it was a filter wheel. It was a very complicated piece of machinery.

But it was all very computer-based and very design-based. But she spent half the summer shadowing the guy in the machine shop who was actually going to be making the wheel. And this ended up motivating so many of her design requirements and decisions. And I think, at least from an engineering perspective, it's very important to understand how that works so that you can not forge ahead beyond the capabilities that exist, and take advantage of the innovation that's happening on the factory floor.

WILLIAM BONVILLIAN: Right. And as we talked about last week, one of the things that Japan figured out in its highly innovative production process towards quality was not separating the engineering workforce from the factory floor workforce, but really integrating them, right? And the engineering community would come on, and its first round of jobs was to understand how the factory floor operated.

So Germany is famous for this. But when there's a problem, when there's a production problem, a swarm forms in these Mittelstand firms. The engineers and the highly educated

workforce team up and are working the thing out together, right? That happens less than the US system. So this kind of integration of the design team and the production team is something that has been organized in countries like Japan and--

AUDIENCE: [INAUDIBLE] consulting firms just sort of build that gap.

WILLIAM BONVILLIAN: Oh, yeah. Right. I'm sure they do. McKenzie is right there on the factory floor, right?

AUDIENCE: Oh, yeah.

AUDIENCE: Well, and what's fascinating is-- at MIT-- have any of you guys taken classes at D-Lab?

AUDIENCE: No. But they've helped me build some stuff.

AUDIENCE: OK. Great. So they're really big advocates of creative capacity building and co-creation, so building products for communities in developing countries with those communities. And I think it's been fascinating that MIT is at the forefront of that for developing countries. And yet--

WILLIAM BONVILLIAN: We've got a developing country right here.

AUDIENCE: Right.

WILLIAM BONVILLIAN: Right?

AUDIENCE: I think companies, particularly like the German style sort of rotational programs for these engineers, making sure that they get experience on the factory floor-- I think, I want to say chemical production plants-- so people who graduate with chemical engineering degrees [INAUDIBLE] oil pipelines, they do this pretty well.

So they go and they rotate and they see the oil pipelines and stuff like that, so if they have to build these complex parts in front of the computer, they go to the site and go and see what's going on. I feel like they have those rotational programs for the established-- I'm going to use chemical engineering firms, because that's where I've heard the most.

But there is this sentiment that maybe touring these factory floors and actually seeing what you're building is going to be really important. But I think the only other rotational programs

that I hear about, when people do internships like this, is in I want to say finance. They do this very well. They rotate you in different sectors. I think Goldman-- all the big banks have rotational programs, where you have your first two or three years. And Visa does it as well. Everybody does it.

But you basically spend a year or two working with a particular team with a particular focus. And then you tour all up and down the pipeline. So if it's asset management, you go top to bottom.

AUDIENCE: [INAUDIBLE]

AUDIENCE: [INAUDIBLE]. Excellent. So if you transition and make sure that these internships that people are getting sort of do more of that, and kind of mimic those models, where you rotate around and see what's available, integrating those pipelines, then you'll have a better idea of what you're actually engineering for and what these design processes are actually supposed to look like within manufacturing.

AUDIENCE: I want to call on Max.

AUDIENCE: So I've been thinking a couple things. One would be that that approach of forcing engineers to actually to basically get their hands dirty-- I feel like it would make them happier, because--

AUDIENCE: Well, a lot of the people [INAUDIBLE].

[INTERPOSING VOICES]

AUDIENCE: A lot of the people that go into engineering, they're the kids who played with LEGOs. And they thought, oh, this is what the engineering's going to be like. And then they find out it's a bunch of CAD drawings and Excel spreadsheets. And they're just like, wow, this is isn't exactly satisfying. I can't speak to everyone's experience. I can speak to mine.

And I know that was one of my reactions. It's still like, yeah, you're designing something that's changing the world. But when it comes down to it, it's still all on a computer. You're staring at a computer for eight hours a day.

And as other people were saying, yeah, it definitely gives people exposure to concepts like machine tolerance and the ability for, I don't know-- you realize that, hey, I can't design something that has design specifications within a femtometer. That's 10 to the negative 15

meters. It's 15, right? I think it's 15.

AUDIENCE: It's very small.

AUDIENCE: It's small. So yeah, I generally agree with the general sentiment.

WILLIAM BONVILLIAN: So Max, how pervasive is the maker movement now at MIT? I mean, I think we have some 40 maker spaces. And Professor Marty Culpepper's or makers are obviously a very talented guy.

AUDIENCE: I do know that a couple of professors in the nuclear department are trying to design a maker space. They're trying to get some support together, some funding together.

AUDIENCE: [INAUDIBLE]

AUDIENCE: [INAUDIBLE]

[INTERPOSING VOICES]

AUDIENCE: Mike Short.

AUDIENCE: Mike Short? How do you know Mike Short?

AUDIENCE: I study nuclear.

AUDIENCE: Beth, I know that you wanted to respond to that.

AUDIENCE: Yeah.

AUDIENCE: Oh, yeah.

AUDIENCE: Could you respond to [INAUDIBLE]?

AUDIENCE: I probably said something horrible.

AUDIENCE: No, no. I just think-- my view of a lot of MIT students is that we've been prepared is like white collar engineers. We're people who want to go straight to the office. And I think part of it's good. We want to be leaders. We want to be tackling big projects. But we also view ourselves as not wanting to get into the nitty-gritty, out in the FRCs in the field, doing the hardcore engineering-- that we've kind of surpassed that and should be doing higher and better things than that.

And then kind of unrelated to that-- well, somewhat related, is demographic change, but changes in people's preferences. I know, personally, I was offered a job in somewhat manufacturing in kind of the middle of nowhere. And so I have a strong preference to live in a city. And so that has made me less likely to [INAUDIBLE] manufacturing outside. And there's not really the opportunities to-- I mean, there are some opportunities to have like the urban lifestyle and also work in manufacturing. But that's becoming less and less possible.

AUDIENCE: I think something I've noticed amongst our responses-- and well, we aren't talking particularly about the skilled workforce. So I was wondering if you could elaborate a little bit more about what training programs or what this experience might look time for the, quote unquote, unskilled workforce, or the non college-educated crowd, as we are going to be transitioning to a question about that momentarily.

AUDIENCE: Yeah. So in my hometown, we're just by a really large shipyard. And so there's a pretty strong apprenticeship program that a bunch of kids are going to school.

WILLIAM Where is that, Beth?

BONVILLIAN:

AUDIENCE: It's the Newport News Shipyard.

WILLIAM Right. That's what I thought.

BONVILLIAN:

AUDIENCE: And so I've seen that a lot of people that I know from high school who have had very successful points in their careers now. They finished their apprenticeship program and are now full-time employees of the shipyard. And that does seem to be an exception rather than a rule. And it seems-- it is very much like the shipyard runs it itself. It's not like wider movement. And it's been really, I think, successful for them as well in having a continuous skilled workforce, and repeating that elsewhere seems like it could be a good idea.

AUDIENCE: So this is--

[INTERPOSING VOICES]

AUDIENCE: I want to hear from Kevin. He actually wants to go into manufacturing.

AUDIENCE: Yeah, yeah, yeah.

[INTERPOSING VOICES]

AUDIENCE: First of all, I don't know about my last year. So before this semester, I was actually taking time off. And for about a year, I worked as a manufacturing operations manager at a digital printing company. It was a small startup, kind of new. But for the first two or three weeks, they had me learn every bit of the process, from picking out access material by hand, to learning all their new software, to understanding how the big wide format printers work, setting up the conveyor oven with the owners-- every part of the process.

And I can definitely say that helped a lot in my understanding of being able to manage the employees in the different departments-- the shipping, the art department, all that-- because I knew it worked. I was in touch with them. I was in touch with the employees. At the meetings we had, it was just the owners and me. It was the owners. There was someone would be there from shipping. Someone some would be there from art. And everybody would say, look, this is great, we would love to get orders out this fast, but shipping can't do it because of these capabilities. And next week, we'd make a change that would make that possible.

Going back to Beth's point about manufacturing not being cool-- this is just my opinion, but I really don't want to kiss up to someone for funding for an idea. Right? I am very happy learning every bit of process in the manufacturing operation, and then being able to lead that. And I definitely enjoyed that the last year, which is why it just kind of reaffirms my decision to go into manufacturing after I graduate.

WILLIAM Kevin, you're going to save us all.

BONVILLIAN:

AUDIENCE: That's the plan.

WILLIAM Right. All right. You get one more question, Steph, because then I've got to get to the last

BONVILLIAN: reading, because the clock is upon us.

AUDIENCE: Oh, this is so stressful. So I'll say, I think-- there it a question that I'll mention that we will not get to debate, but I hope that everyone sort of reflects on this point, which is a point that Chris raised. She says, how do we expect domestic policy, job creation, and manufacturing to change under Trump's administration?

Obviously, that's something that we'll sort of witness, unfortunately, or-- no value judgments here. But I do think it was important to raise that is a reality, as we all know. The question that I

really want us to flush out is from Lily. And she says, would this not be an ideal time for a very effective national advertising campaign promoting technical schools and starting to promote technical skills? If the administration intends to create increased manufacturing jobs, won't it need a ready workforce in a few years?

AUDIENCE:

I'll jump in on that. I think, yeah, it's definitely a good time. I think we're kind of in a pseudo college bubble-- not to say that college isn't valuable. But it's not proportionate to the amount of people we need in the economy for jobs. So you need blue collar people that would be educated at a higher university and grad students. And so there is a huge divide in that people just don't go with the blue collar jobs because they don't seem valuable.

So a lot of it is based on is this a valuable profession for me to go into, especially because there are some people who, if they want to get very practical, street smart, manufacturing skills, they might want to go work in manufacturing versus actually studying a mechanical engineering degree. And so it's how do you make those jobs valuable, but also a good use of people's time. Yeah.

AUDIENCE:

Yeah. Thinking about that, [INAUDIBLE] case study in education [INAUDIBLE] high school. If you look at Sweden's education system versus the US, and in Sweden, any high school teacher needs to have a master's degree. And becoming a teacher, a high school teacher, is like the job that people want to enter.

And it just makes me think about and consider how much of our perception of a job and how much demand there is for certain jobs is flexible. And it's not necessarily-- well, the value you add is as perceived by people in the country, right? So would it help even just to have a PR campaign for manufacturing jobs? And would that even be enough to shift people's behavior towards it?

AUDIENCE:

But I mean, that's a PR [INAUDIBLE]. And I had dinner with this guy who's the president of an energy company in Australia. And he talked a lot about credibility, not just being credible. So the GE commercial, you could hear it and see, oh, yeah, well, I don't really trust it. I don't believe it, because I know you're marketing to me. Right? And this is a big thing business, especially today, because people can sense bullshit, right?

It's just like, yeah, it's not real, because you used to be like, oh, yeah, safety's a really big priority. And he would go-- he was part of this mining slash energy company with oil. And he

would go in and he wouldn't wear his safety equipment. And he would go on the job and in the field and everyone would see him not wearing safety equipment. And then he'd go and push for-- oh, yeah, let's do-- we need to be very safe, guys. And they're like, well, you're the boss, and you never do any of this. Why should I listen to you? So it's like, how do you do it in a very credible way that people can actually see people that are successful? Because right now, who do you see as successful, right? It's mostly some college educated-- I don't want to say white male, but it's definitely not women and minorities, really. Yeah. Good point.

AUDIENCE:

Well, I had a lot of considerations going into this question. One is, is wistfulness. or hopefulness. I just wish that, with the energy that was generated during the election and the promise of jobs, and you saw a lot of people-- I think there's anger, but also hopefulness. Like yes, we're going to bring back manufacturing jobs.

So then build on that. Identify-- it would be excellent if the administration could pinpoint what sorts of sectors they want to promote and incentivize, and then create an advertising campaign.

I know when I was younger, I used to see the-- I think the military divisions have really excellent advertising campaigns. I saw it, the Air Force, and be like, oh, man, I want to go into the Air Force.

[INTERPOSING VOICES]

AUDIENCE:

Have you seen [INAUDIBLE] Marine commercial? Have you been targeted on YouTube yet? It's so good.

AUDIENCE:

I don't watch enough TV these days. But I think that this would be an opportune time to do that, so that if you generate manufacturing jobs over the next couple of years, as they promised or intended-- and more manufacturing jobs have come back over the last few years, as we've seen. So then have that ready workforce.

Also, I'm from a rural area, a farming area in Missouri, where a lot of jobs have been lost over the last decade. Most of the people I went to school with don't have the money to go to a four-year university, and they don't have the money to not make money for four years. So something that's more short term, like a one-year, a two-year technical program is much more in line with what they're able to do. Those were the considerations.

AUDIENCE:

Yeah. And then I do think what else needs to be considered is what exactly would we

recommend to train people in at this point? What are the-- because you don't want to train a bunch of people in something that is no longer useful in five or 10 years. So should we be teaching people how to code? Should there be programs in using complex robots?

I don't know what to expect. And I think that's a challenge.

AUDIENCE: No, it should be targeted. Yeah.

**WILLIAM
BONVILLIAN:** So I spent some time with Sanjay Sarma earlier this afternoon. And he's a--

AUDIENCE: [INAUDIBLE] what does he do?

**WILLIAM
BONVILLIAN:** He's a professor of mechanical engineering, and has spent a lot of time creating a lot of the RFID capability, and did a lot of work in manufacturing. But he's leading MIT's online education efforts. So he leads MITx and the Office of Digital Learning ODL.

So that was his question. We can take these new platforms we've built, and they could be valuable. They could be new assets. And we could create blended learning models with community colleges, for example. But what is the content of the education? How do we figure that out? Right?

And it's really a big, important question. And that's his central question at this point. He's ready to do it. But he's got to figure out a process by which to get to the answers of what are the most critical skills to educate for? Obviously, they're going to vary to some extent by sector. But that's a really big question. So Steph, give us a closing comment.

AUDIENCE: I am prepared for this.

WILLIAM I know you are.

BONVILLIAN:

[LAUGHTER]

AUDIENCE: The haircut-- yeah, this is what I want to study, right? This is what I love. And I think in particular [INAUDIBLE] I was doing research that was funded by [INAUDIBLE] here at MIT D Lab, Wellesley, and some organizations in Thailand to research precisely how you do creative capacity building and increase civic participation and innovation in ways that really support

collaboration and are responsive and understanding of the political and economic contexts. Right?

And we did this research in two villages in Thailand. And I think preliminarily, the most important outcomes of this study were realizing that a lot of technologies fade rather quickly, right? They're no longer useful. They become outdated. They fail to run. And I think we do a really great job of studying this in the developing world when we ship tools to other places about how they're no longer modular. And I think we could apply that sort of same line of reasoning here to the United States about the ways in which we treat critical thinking education and ways in which we make our education systems modular and understandable for all at every point, rather than teaching particular skills that may be outdated, because then they'll end up in crises like I had two Saturdays ago-- crying in my room, saying, why can't I get this problem?

And I don't know that the kind of support system that's necessary for an initiative such as blended learning is [INAUDIBLE] currently. And that's why I think it's so important to really assess cultural factors, and also questions of support as we move forward with how to improve the innovation and manufacturing harmony.

**WILLIAM
BONVILLIAN:**

All right. Thank you. All right. So I'm going to just summarize this closing reading. We've talked a lot about the problems. This has been one attempt at a fix.

So these two reports came out in 2012, 2014. They were prepared by a collaboration between major industry CEOs and a whole range of sectors, and a group of university presidents who had particularly strong engineering links, including MIT's president.

So both Susan Hockfield at MIT and Rafael Reif at MIT were both co-chairs, university co-chairs, of these two different reports-- Susan for the 2012 one, Rafael for the 2014 one. So there's been a very major focus on these issues at MIT. MIT did the production and the innovation economy. It was, frankly, educating the administration of what the issues were.

And then, surprise, the Obama administration came back and said, all right, put your money where your mouth is, and help us pull these reports together. So I had the privilege of being part of a delegation of MIT folks to help in preparing these. And it was a fascinating experience.

So there were essentially four recommendations that came out of these reports. There are

transformative technologies. And could we develop, to achieve these transformative technologies and production, technology strategies that were linked to the R&D system?

Could we implement manufacturing institutes and network the manufacturing institutes organized around these transformative technologies? Could we have, as part of the role of these manufacturing institutes, they would play a role in demand-driven workforce solutions? And then finally, could we develop a technology scale-up policy to deal with this scale-up problem?

So these reports really focused on this stuff. They argued that we need innovation-based efficiency gains to compete with lower cost, lower wage nations. There's no substitute for that. The macro factors don't necessarily give this, those solutions. We've got to put the innovation system on this problem. Right? There's no getting around it. It's time.

So there's 14 advanced manufacturing institutes now. They've been set up all over the country. They are collaborative. They are industry, university, government. They are federal government seed funding, but often overmatched by industry with seed funding as well from state and sometimes regional governments.

They have a big test bed roll. So they bring in the small and mid-sized manufacturers and put them in as part of the innovation system. Right? They're connecting the small and large manufacturers, just as in the German fraunhofer model. They have a big test bed role in testing technologies out so that a small manufacturer would know how to play with them, know how to work with them.

And then they're organized around these potential new production paradigms. They're cost-shared, as I said, between the federal government industry and the state government. So they're very collaborative.

An example-- what does advanced manufacturing technology look like? Here's a printed car. Right? Concept to print, six weeks, 500 parts-- took 24 hours to print this. That's a Shelby Cobra. It's electric. It's battery-powered. Pretty interesting, right? It gives us some idea of what some of these capabilities are going to look like.

What's the stage that the institutes are supposed to address? And we've seen designs like this earlier in the class. But we've got basic R&D, government support of universities, a gap here, and then a private sector role. And the gap occurs-- basic research, proof of concept, then

actual undertaking, kind of the initial production stage at a lab kind of level, capacity to produce the advanced prototype, and the capability, really about here, to operate in a production environment, bring the technology to production. That's where the gap is. It's in these stages here. Right? There's a missing link in the innovation system. Remember, we talked about doing a gap analysis of the innovation system and filling the gaps in? That's exactly what these institutes are attempting to undertake.

And here's the organization of them. This is a very complex organization. Right? So you've got an institute, which has prototype labs. It has shops. It has research facilities. It's got a computerized lab for simulation and modeling. These are shared use facilities, where small and large firms can collaborate together.

They're bringing in universities for engineering capability from the university level to help in the innovation stage and technology development. They're bringing in community colleges on the workforce development side.

Over here, they're bringing in large manufacturing firms, small and mid-sized. And a number of them are starting to think now about startups. How do we get them into this mix? And then the support system-- federal, state, and local-- and economic development organizations are all feeding in here. And then above this, we have 14 of these institutes now. Could we create a network of them so that we get learning across the system?

So that's essentially the organizational design. It's a very complex model. What does an R&D agency typically do? It gives an award of \$300,000 to a principal investigator. As a Defense Department official told me, this is like standing up a country. You've got literally more than 100 actors involved in these manufacturing institutes. How do you coordinate them? How do you pull these things together? We've never tried to do anything as complicated as this in the R&D system. It's a real challenge.

So this is the first group of manufacturing institutes. You can see that they're pretty distributed across the country. And then we've had five more institutes since these were stood up. Here's what we're working on. These are the territories of advanced manufacturing.

So we've got 3D, printing digital manufacturing and design, lightweight and modern metals, next generation power electronics, which is largely wide band gap semiconductor-- completely changes power electronics, but a lot of other things too-- advanced composites, photonics, flexible hybrid electronics. MIT is leading the advanced fiber institute, which is completely

revolutionary. The US lost the textile sector ages ago. So this is an idea, bringing entirely new functionality into fiber and textiles.

So the idea here-- my shirt is my cell phone. My coat is my laptop. It's just full of communication fiber, right? But why can't you put a whole new level of functionality into fibers and textiles, a whole kind of new utility, and a completely invented sector? As Yoel Fink, who's head of that institute, reminded me on many occasions, and his colleagues as well, said, Egypt came up with cotton about 4,000 years ago. And that's about the last big thing that happened.

[LAUGHTER]

WILLIAM BONVILLIAN: Right? So this crowd is completely trying to rethink-- and they've got a fascinating mix. They've got Apple in there. And then they've got Nike and Adidas. And then they've got Under Armor. And then they've got a bunch of textile firms that still remain in the US. And then they've got fashion design shops.

And it's a really interesting mix as they try to rethink an entire sector. Smart men-- I'm sorry. Go ahead, Max.

AUDIENCE: What is next gen power electronics?

WILLIAM BONVILLIAN: If you did wide band gap semiconductor, you lose-- you have much more efficiency in the power connections. And you have much less power loss in a switching process or a connection process. Right? So it requires a new kind of semiconductor to undertake this. But it could be in everything, and very perfect pervasive, huge power savings, much more efficiency in production as a result.

There's five more institutes that were named at the very end of 2016, beginning of 2017-- Bioengineering for Regenerative Medicine, Assistive Robotics, Modular Chemical Process Intensification-- in other words, rethinking the whole chemical engineering process system to radically reduce the number of stages-- Sustainable Remanufacturing Recycling. And then the Department of Commerce had an open competition, and they came up with biopharma manufacturing. There are major new advances in biopharma manufacturing for continuous production.

So it's a very interesting list. Right? What's interesting about the US list is that it covers a wide range of stuff, where there are potential advances it could be quite powerful. Some are going

to work. Some are going to fail.

But overall, it's a pretty interesting model. If we could get these technologies stood up and a workforce that's ready to use them, then you really might have something pretty significant. And as you remember from that matrix chart I had before, these are designed to stretch across a whole series of industries, not just a single industry. Beth?

AUDIENCE: Are these vulnerable to being cut? Or right now, they have secure funding?

WILLIAM I'm definitely worried. We'll see.

BONVILLIAN:

[LAUGHTER]

WILLIAM The funding's by no means secure. But Congress has passed legislation supporting this on a completely bipartisan basis. There are strong advocates in both parties for these. Senator Blunt from Missouri is a very strong advocate for example, has been a real champion of this stuff.

BONVILLIAN:

So there's a lot of Congressional support here, mainly because members of Congress are seeing what's been happening in their Congressional districts. So I think this is a more survivable model. And what's wrong with this? I mean, this is a total public-private partnership with the private sector dominating and leading and making by far the largest contribution to the funding. Right? So this is not some federal subsidy program. This is very cost-shared.

So I think it may be survivable. We'll see. MIT is in nine of these 14 manufacturing institutes in one way or the other. We're very active in about four and leading on one. So there's now a whole community at MIT of leading researchers that's into this stuff. And MIT had not been in this area for a long time. It just wasn't-- you didn't get R&D funding for manufacturing. Right? This is a whole new kind of territory. So we'll see. Hopefully, it'll work for you, Kevin. Maybe some others.

AUDIENCE: We just answered our last debate. This is what we designed the technical training programs around.

WILLIAM Yes.

BONVILLIAN: