WILLIAM BONVILLIAN: All right, we're going to do two in a row. And Kevin has got these. So first we're going to do a snapshot on, gee, could the Defense Department-- you remember those guys, with that connected model. Could they play a role, here? Is there something useful they can do, here? And then the second is on this new RPG-- fairly new-- ARPA-E model that's come about.

So this is Dorothy Robyn. She was the former Deputy Undersecretary of Defense for something called Facilities and Environment. And she worked for, you know, Ash Carter.

DOD had the largest-- it's the largest facilities owner in the United States. 507 installations and bases, 300,000 buildings, 2.2 billion square feet of space. That's interesting. Right? Maybe they're a test bed. Right?

And, you know, they do consume more oil than anybody else in the United States-- 1.7%. That's not a lot, but still it's a lot of oil. And they spend a lot on energy every year.

So maybe they've got an interest in some of this. So, sure enough, DOD actually thinks it's got an energy problem-- for some pretty good reasons. They understand that they have a strategic problem having to do with worldwide energy supply.

The United States is profoundly dependent on its oil supply. And that is an international market. We probably spend a third to a half of our defense budget on protecting what the military calls their "lines of communication" around oil-- i.e., their oil-supply system. So, cleverly, the oil industry has managed to get the American taxpayers to foot at least $250 billion a year, protecting their supply system. That's pretty clever-- a signal of a politically powerful legacy system.

So there is a deep strategic problem around oil supply. And then there's a profound tactical set of problems that-- you know, they've been engaged in two Middle Eastern wars in the past decade, largely around related to oil supply. And their own internal energy supply lines created most of their casualties. Right? That's why we lose people, in these painful supply convoys. It forces the army in particular into a terrible tactical position of having to defend these fixed

points and concentrate forces to defend these fixed points, in an asymmetric war where you don't want to have fixed points. You want to be part of communities and populations.

So essentially the oil-supply problem has completely counterdicted everything the army knows about how it should fight asymmetric conflicts. It's forced it into offending long supply chains to fixed points, which is not a tactical position it wants to be in. And it's, in turn, forced many casualties, as a result.

So the Army and the Marine Corps wants to get out of this box. They want more mobile, flexible, tactically free forces, to be able to sustain the kind of models they've developed for optimizing their warfaring capabilities. So they've got a strategic problem, a tactical problem, and then they've got a big facilities problem.

DOD has lots of aging, old facilities, on old, long-established bases, often built in the World War II time period or the Cold War time period. They have been, for the last-- since the end of the Cold War-- under a significant amount of cost pressure. How can they get their facilities' cost down?

So that's where Dorothy Robyn, who has the facilities responsibility at DOD, where she came in. Interestingly, DOD every year gets $20 billion in something called "milcon"-- military construction. That's for rehabbing, repairing, upgrading, and undertaking new construction for its facilities and bases.

That's, like, a guaranteed revenue stream. And you can do a lot of interesting things with a pretty guaranteed revenue stream. So one of the things that the Defense Department was attempting to do is really take advantage of this revenue stream to do significant facilities upgrades, in terms of energy uses. And so that was one of her major projects, there.

So DOD could be a very interesting testbed and a very interesting initial market for a suite of new energy technologies. Right? So DOD Is not going to do carbon capture and sequestration. Right? That's not its problem. But it sure is interested in getting off the grid. Right? It believes it has a terrible cyber security problem, by being on the grid. It wants off.

It significantly wants to reduce its energy costs. It's ready to experiment with renewables, partly because of the grid strategy, probably to establish more mobility and get off fossil fuels line of supplies. It's got an incredible number of vehicles, both for military purposes and unmilitary purposes. That again is another testbed opportunity.

So the idea here, as her testimony laid out, to one of the armed-services committees, is that DOD actually could be a partner in an energy-technology strategy, as a demonstration and testbed kind of center and an opportunity to introduce certain kinds of new energy technologies. Huge interest in batteries, for example.

So ARPA-E was a gap-filling attempt. The Department of Energy innovation system, it's kind of what it looked like before ARPA-E came along. Right? The red stuff is the new stuff. The black and white slides or boxes are what was there before.

So, before the new stuff arrived, the Department of Energy had big, fundamental research organization, very basic research in areas like particle physics and chemistry. Famous Vannevar Bush basic research entity-- the DOE Office of Science. The great bulk of the energy laboratories reported through the DOE Office of Science. They took up about 60% of DOE Office of Science budget. It was about $5 billion a year.

The energy labs-- one of the largest armies PhDs in the world. Right? An incredible 12,000 army-- great majority, physicists. There may be some engineers in there.

It was on the wrong problem. Right? It was on the historical nuclear-weapons problem. So, of the 14 energy labs, the nuclear-weapons laboratories had about 5,000 of that army of PhDs. The NREL laboratory, renewable-energy laboratory, had 340 of the PhDs. Right? You can see what the imbalance here is. It's not the right lineup. So it was kind of, a lot of the talent was on the wrong set of issues-- or at least not the new set of issues.

There was an energy-efficiency and renewable-energy entity, had about a $2 billion budget. There was some other applied-energy offices. That was the landscape. And then a huge nuclear security kind of weapons-oriented part and a big cleanup, nuclear-cleanup, part of the department. That was kind of the department.

Something that happened under Sam Bodman and then Steve Chu and then Ernie Moniz is that that whole picture of that department got reorganized. One of those pieces was ARPA-E. We'll come back to this slide in a minute. ARPA-E was organized to bring a DARPA-like model-- a breakthrough energy research-- into a structure that didn't do that. Right?

The applied agencies worked primarily with established industry. There was nobody really working on the breakthrough side. So, if you happened to think that you need a lot of breakthrough energy technologies to solve the climate problem, you probably need something

like this.

So an interesting process got put together, to get that assembled. You know, Max, you asked a very good question earlier-- how come it's only $300 million, when DARPA's $3 billion? Those of us who were involved in advocating and supporting the legislation, we wanted a much larger budget, frankly, a $1-billion kind of budget for ARPA-E-- and have never politically been able to get there.

But, nonetheless, I would argue that ARPA-E has actually been a pretty remarkably successful entity. So ARPA-E does all this stuff that we've talked about for DARPA. It's got that model down-- flat, nonhierarchical, empowered program managers. They're called "project directors." Streamlined approval process for both hiring and for contracting.

It's right-left. It's challenge-based. It only wants to do breakthroughs. It's not going to do incremental work.

It uses island/bridge. In fact, Arun Majumdar, who was the first head of ARPA-E, who's one of the most talented science leaders I've ever seen-- remarkably talented guy-- he had been-- Steve Chu, the energy secretary-- he'd been Steve Chu's deputy at Lawrence Berkeley Laboratory. So, when Arun moved to Washington, he lived in Steve Chu's basement for six months. So there was no island/bridge problem there. Right? [LAUGH] You know, they were only a floor away. There was extremely good communication between the two. That's the best island/bridge example I know of. [LAUGH] So I try to bring it up.

But, interestingly, ARPA-E, it didn't have that connected energy system for innovation. Right? Because the Department of Energy doesn't do any procurement. They don't buy batteries. They don't buy electric cars. You know, they don't buy this stuff.

So DOD buys their first round of products. It can be an initial market creator. That's one of the advantages DARPA's got. How does ARPA-E function, when it doesn't have that follow-on capability embedded in the department, which it's located?

So it's had to come up with a whole bunch of new approaches that have really been quite interesting. And I list some of them in this piece that I did with a friend and a DARPA expert, Dick VanAtta. They did a lot of work on how to sharpen their research-visioning process. They definitely followed that research-visioning model.

It's not only, is this a cool technology, but is this a technology that is not only potentially a breakthrough, but could it actually scale up? Is it plausible-- do we have a plausible pathway, by which this technology could come into the marketplace? And that's definitely part of the research visioning that ARPA-E undertakes, in a way that DARPA doesn't really have to because it's got military customers often.

It's done a remarkable job at building a support community. So ARPA-E, just for one example, it does what's now become probably the most important US energy technology summit every year. They get 2,000 to 3,000 people showing up at this. Every major energy firm, every venture-capital firm, they're all there for, like, a three-day session. They have great speakers-- and amazing technology.

In other words, if you do technology for ARPA-E, it's going to get showcased. It's going to get presented to this energy world. It's going to be shown off. They're going to help you take that next step.

And, interestingly, in the first summit, when they put out their first, you know, offer of-- you know, for proposals-- which didn't specify areas they wanted to research in; they just had an open proposal. Hi, energy community, out there-- send us your best stuff-- they expected to get about 400 proposals. Instead, they got 4,000. Right? Because there was so much interest in working with a DARPA-like thing.

So they were drowning. They had to invent a whole review process, to manage all that. But, interestingly-- and they could only approve a modest number. But they invited all the best proposals-- a much larger number-- to show up to their first summit and present. Which helped build a community. You know, the community felt, hey, these guys are going to look out for us. And it created a whole community interest in what this thing was going to be that has been really quite successful.

So they've got a strong support community in the venture-capital community. They've got strong university support. They've got established companies that are working with DARPA-- supported research and firms. It's pretty interesting.

The most interesting thing they've been doing is on the technology-implementation side. And here, they created their own commercialization team. So there are these project managers, and they-- you know, they're empowered, DARPA-like project managers. But, on their team, they pull in somebody from ARPA-E's commercialization group. And these are people with,

like, expertise in getting venture capital and commercializing technology. They know how larger firms do technology commercialization. They even have somebody who's expert at military contracting, so you might sell it to a DOD market.

The commercialization team has a member that's part of the technology group. Right? So commercialization is thought through from the outset of an ARPA-E technology project. Because, again, they don't have this big procurement budget. They've got to find more creative ways around it.

And the greatest compliment so far to ARPA-E and its success-- DARPA has now copied the model. So, like, the parent has now copied the child. And DARPA, earlier this year-- or last year-- hired ARPA-E's head of their commercialization team to set up a commercialization team at DARPA. So, interesting. Right?

So those are some of the efforts that ARPA-E has been making. And Kevin and I were talking, earlier, but ARPA:E did a very thorough, tough-minded evaluation of all of its research budgets and then issued reports in August and September. And it's a pretty fascinating story.

You know, as we know from this class-- and Kevin and I were just talking about this-- technology standup takes a long time. Right? 1947, we do the first mainframe computer. You know, 1993, the internet and desktop computing are scaling. That's a long time. Right?

Fracking happened a lot faster than most technology standups. That was a 15-year project. It's paradigm-compatible with the legacy sector, so that helped, but that was still a 15-year project.

So seven years is much too short a timetable to be evaluating whether these energy technologies are going to scale. But, in terms of technology advance, and in terms of attracting additional funding from nongovernmental sources, ARPA-E has had a very good track record-- as evidenced in these August and September reports they've put out.

All right. All yours, sir.

MARTHA: Can I just ask a question?

WILLIAM BONVILLIAN: Please.

MARTHA: Didn't they announce that basically the companies had attracted about as much outside funding as they had spent since our ARPA-E began?

WILLIAM BONVILLIAN: Yes. And that was composed of two sources-- other federal R&D, or--

MARTHA: OK, OK.

WILLIAM BONVILLIAN: --financial support from allied companies or from venture-capital firms. And we're going to talk about the venture-capital model in a bit.

MARTHA: OK. Sorry for interrupting.

WILLIAM BONVILLIAN: No, but it was a good point to make. Thank you, Martha.

KEVIN: OK, so, going back to the testimony by Dr. Robyn, she stated that all these critical facilities that the DOD depends on for running operations across the board are so vulnerable. Why did they let it get to such a point where, you know, someone needs to tell them, like, hey, you know, we should innovate in this regard, to prevent all that from happening. And, taking those lessons learned, how should the DOD or any department really prioritize any proposals that come forward to it?

PERSON: Do you mind rephrasing the question?

KEVIN: Yeah. So she said these critical systems are really vulnerable. Here's my proposal. In the future, or in anyone's opinion, how should any department and particularly the DOD prioritize its resources, based on these proposals that they get, in order to prevent such vulnerabilities from occurring?

STEPH: I can't imagine that this was published without some of those vulnerabilities being patched.

MARTHA: What do you mean by "patched"?

STEPH: Like, it does not occur to me that the government would allow-- or, you know, the-- what is she-- the Deputy Undersecretary of Defense--

MARTHA: To publicly--

STEPH: --to publicly announce that these vulnerabilities exist within their system, in their infrastructure,

without them first being patched. Right? And I know that a lot-- could you talk a little bit about that, Bill? Because--

WILLIAM BONVILLIAN: Well, I mean, she's--

STEPH: --it says that it's hold until released.

WILLIAM BONVILLIAN: Right. She's testifying in front of the Armed Services Committee, and they want to know what's going on. And a witness has got an obligation to come forward with what the state of affairs is. You know I don't think these were probably classified-- I know these weren't classified issues, because this was an open hearing.

But she's got a responsibility, as a governmental official, to tell a congressional committee what in fact is going on and what the issues and vulnerabilities are. So I think she's doing her job, and the congressional committee is doing its job. It's got to probe and find out what the problems are. I'm not sure that's a great answer to your question.

STEPH: I guess-- does that not-- I guess, to follow up, would that not set us up for more vulnerabilities, if we openly acknowledge that that's something that we're concerned about? Just-- and would it not be a problem that we will find ourselves more into, if we admit to such vulnerabilities in a public setting?

MARTHA: Maybe it's already obvious, if it's been in the press, et cetera. People dying-- yeah.

STUDENT: And then what they do is particularly surprising.

STEPH: I don't disagree, but I think it's different to have a deputy undersecretary admitting it-- is my point.

KEVIN: I think, following up on that, if, you know, it's not a surprise to anyone, why are other projects prioritized over preventing this from happening? If it's like, oh, well, of course, they're vulnerable to cyber attacks, and these facilities are falling apart. You know, we were just talking about, the dependence on oil causing a lot of problems. Why not innovate in that area?

STUDENT: Well, I think part of it goes back to the funding, from that graph. You remember that graph, the graph about funding and oil prices that [INAUDIBLE] follow the same trend? So, like, if funding isn't really steady, you can't really innovate very well. It's hard to maintain facilities.

KEVIN: But you said they get a $20 billion--

WILLIAM BONVILLIAN: They do have an annual $20-billion military-construction appropriation that's potentially an interesting revenue stream that you could finance off of.

STUDENT: But that's just DOD. Like, other departments, they still have these problems.

WILLIAM BONVILLIAN: Right, But DOD is the monster in the room. They're the ones that really have the facilities.

STUDENT: Also, I wonder about the distribution of the quality, I guess, in facilities or infrastructure. So I can imagine, not all these 300,000 buildings are really falling apart and in disrepair. But I think maybe it's just, they don't like that there are a number of buildings sort of on this lighter end of-- kind of built in World War II-esque, and they haven't really been upgraded from a construction or systems point of view.

And I would argue that, like, the $20 billion or however they're getting yearly to upgrade these services is adequate or kind of serving them well, such that those are-- like, that's your patch. And it's not really an issue of national security, in a sense, because this is a distributed problem, kind of over the DOD network, rather than, like, all right, all of our systems in Virginia or in this particular area are subject to cyber attack and are vulnerable. It seems like-- like, it's too big of a problem for it to be actual information for her, you know, not to be able to testify about it. This isn't a national-security interest, in that it has to be protected.

STEPH: Yeah. And, to your point about the size of the budget, I'm looking at the 2017 report on infrastructure management, from the Government Accountability Office. And it says that they expect the DOD estimated replacement value to be $880 billion. So. That's a--

STUDENT: What do you mean by "replacement value"?

STEPH: Well, that's what they're-- for the infrastructure, for the DOD, that they need to improve [INAUDIBLE].

STUDENT: That's a lot of money.

[LAUGHTER]

So that was just-- I guess that was just released for fiscal year 2017.

STUDENT: Yeah. I mean, I don't think it's too much an issue that they released this. There's this other thing called Zero Days, which is actually things that you can hack into infrastructure systems. And that's more serious.

What they do is, they will report it to the agency. And, because they know agencies will get lazy, if you say you're not going to do anything they say, I'll give you x amount of time until I do report it publicly. And I think this was an issue that they already knew it was OK to say publicly. And so I'm not too concerned with that.

On the issue of actual, oh, this is a problem, I think it's just more that it's a big government. There's a lot of problems. And there isn't really going to be-- you know, nothing's going to be perfect. And so they're just trying to bring light to it, so they can put funds to it.

And things do precipitate, especially with organizations where-- I mean, this happens with people all the time. Right? You really don't know what you're going to do, like, a day from now. Right? Or a lot of things will add up, and they'll get past saturation points. And it's also just a big legacy sector, so there is going to be issues.

AUDIENCE: Didn't you ask the question of how should they prioritize?

KEVIN: [INAUDIBLE]

MARTHA: Yeah.

KEVIN: [LAUGH] You know, where should those $20 billion go, every year?

MARTHA: Mhm?

WOMAN: I just think it's hard, because, to most people, $20 billion seems like it could solve a lot of problems. Like, that seems like a lot of money. But, I guess, when you spread it across all the facilities that they have, to make a real impact you really need to pick specific things to focus on. And then, I think, a lot of politics can come into, like, who's getting the money and how they're allocating it, because there's not enough for every base to get an upgrade. And so I'm sure that's an additional challenge.

STEPH: The report says 562,000 facilities worldwide, at 4,800 sites. So that's steep.

STUDENT: $20 billion?

STEPH: Yeah.

STUDENT: It's not too much money.

WILLIAM BONVILLIAN: Kevin, how about a closing thought on Dorothy Robyn's testimony?

KEVIN: Well, I'm curious to see how the proposal she laid out has progressed since it was made in 2012. I would hope that more people bring attention to this-- like, hey, you know, we should innovate in these other things that aren't just, like, weapons. Because the development of other projects depends on the development of those, as well.

WILLIAM BONVILLIAN: Right. And I think it's fair to say that she and colleagues at DOD actually made significant progress in using these facilities as, in effect, test beds and demonstration centers for new technologies. And, because this is essentially cost-saving and security-related issues, there's good reason to think that, under the new administration, a lot of this will continue.

Let me turn to the ARPA-E piece. Questions for us, on that one?

KEVIN: So, you know, since you said they just released a report, analyzing [INAUDIBLE] projects on the research and the relative success of that, and because we have evidence files [INAUDIBLE] DARPA has been, why don't we really hear about any other DARPA qualms? You know, they mentioned that the Department of Education was considering ARPA-E, that the NIH was considering their research models depending on-- [LAUGH] that sort of mimic DARPA. Why aren't innovation models like the ones in DARPA and ARPA-E being utilized in other fields?

STUDENT: It's possible that-- this is just an opinion, and I have no facts to back it up-- but--

[LAUGHTER]

--it's possible that maybe some of the challenges that are solved by DARPA and ARPA-E, they don't necessarily translate as well to social problems, like Department of Education. So with education, it's less of a technical problem. And maybe a lot of it's more, how do we manage people, how do we determine what's a good versus a bad student, good versus bad teacher, et cetera. So I'm not sure if it would fit as well. Again, opinion.

KEVIN: To add, I think education in particular would also be considered a legacy sector. And to stand

up, you know, a DARPA-like model for education would be to completely undermine the education system in the United States. And that would require the undertaking of not only the education system in terms of national standards but also a reframing fundamentally at the state level of the ways in which we conduct education policy.

And that, I think, from a reframing the conversation nationally, would be an immensely difficult undertaking. It would be politically-- I mean, I don't know if "politically unviable" is the right word, but it seems to me like it would be politically insurmountable. Because you're now threatening, you know, states' rights.

PERSON: Why does it-- why is it an undermining of the education system I mean, the--

STEPH: [INTERPOSING VOICES]

PERSON: --defense system.

WILLIAM BONVILLIAN: Let me just give a little bit of background, because I was involved in some of this. And it never happened. And Congress was never interested in funding in it. And part of it was, you know, what does the Department of Education-- which is essentially an entitlement-administration organization-- what do they know about technology policy in education? Right? But, with the development of online capability and computer-gaming technologies, a whole new raft of technology options has entered the education field.

So there was a fair amount of thinking that maybe there was room for a technology-breakthrough entity in the education space. The education space is also notorious for conducting almost no R&D. Right? Almost zero. Right? It's tragic.

KEVIN: I would--

WILLIAM BONVILLIAN: And how are you going to transform a sector without, you know, undertaking technology development and research and development on it? So, agree, it's threatening, right? Online education and blended learning are threatening models to establish systems-- no question about it.

But this was actually, I think, an interesting idea. The problem was, who's going to find the right technology crowd that would really create the kind of breakthroughs that a DARPA-like entity could do? And I think that was more of the challenge.

KEVIN: And you're saying it's making threats to establish education models. Is that necessarily a bad thing, wherein, you know, we see the US rankings are way below--

WILLIAM BONVILLIAN: No, I'm not saying it's a bad thing at all. I think the whole system needs to be changed. But I agree with you, Kevin. And this would be a tool to try some of that with.

STUDENT: And it's the big disruption thing. It's like-- it's like Uber. So imagine, like, if you really affect the teachers' jobs, there's all these unions. Right? So, like, now a kid can go and, like, he doesn't-- he still needs a teacher, but now you've kind of made them very uncomfortable. So you can get the amount of push-back. So, when you create this system, you have to figure out how you're going to make it so that the teacher doesn't feel offended. I mean, Kahn Academy did a really good job of this, of, like, OK, well, now you can spend your time doing what you do, in the classroom. But even then, how are you going to get mass support? And I still don't know what their numbers are like.

STUDENT: Why is the kid uncomfortable?

STUDENT: Not the kid, the teacher. Because there's unions. So this is especially important in, like, the-- Steve Case, the guy who made AOL. He made a book called *The Third Wave,* which is, like, you know, the internet entrepreneurs that will affect physical structures and not just web 2.0 that is on Facebook and Snapchat, the people that would create systems that interact with people like Uber, they don't just make a technology. They have to focus on the legacy history of the people in that organization.

So, when you make an Uber, you have to worry about the taxi-cab drivers who paid $1 million for a medallion. And this is how they're supporting themselves, and now you're going to disrupt it. And also, what's going to happen to these drivers? What about union problems? How do you ensure safety, as there's been several concerns. So it's not a tech--

These aren't-- I think for DARPA and ARPA-E, there's a technology issue. Let's do the technology. For these issues, it's more of a, this is very much a people technology. Right? Like-- And most politicians-- Michael Bloomberg, Bill Gates, who's a billionaire, which you all know--

WILLIAM BONVILLIAN: But, Martín, there still have been-- look, I mean, how many technological disruptions of education have there been? I mean, we came up with the printing press in, what, 1562?

[LAUGHTER]

Right? That was a big one. Right? Books-- we figured out books. That's about it. Right? That's pretty much the change.

So applying this whole new information-technology online world to the education system, those are profound technology-- and, I agree, social and learning challenges go with those. And they are threatening to establish communities. I agree completely.

But I do think, interestingly, certainly for the first time in my lifetime, I've seen an opportunity for significant technology entry into a classic legacy sector. And so the idea of putting a DARPA-like thing around that, that was an interesting idea. Right? It just hasn't happened.

STUDENT: I think I'm going to push back on this a little bit--

WILLIAM BONVILLIAN: Please.

STUDENT: --the idea that education doesn't have a DARPA-like model. Like, the rise of charter schools, I think, has really disrupted how we think about the system of public education. And you used to really just have public versus private, but now you have private and, like, quasi public charter schools that receive federal and state funding but, like, do state testing but don't do some other things. And they have the elements that you think you get in a public education, which is, like, the group environment, but they focus their classes and they structure them differently and they do a whole bunch of other stuff, because they don't have to adhere to kind of all of the regulations that come from the state and the federal government.

And so I would say that education has-- it's like a distributed-- it is a distributed system, because it gets, like, more state by state than, like, really the Federal Department of Education-mandated things. But also, in charter schools and things like this, you have opportunities for different models that are-- like, people are already testing out, and you're already seeing this disruption that Martín is talking about, where you have these entrenched public-education systems, but now you're having this rival charter school that now comes in and kind of disrupts teachers' unions and things like that.

WILLIAM BONVILLIAN: All right, so I'm going to-- you know, I'm going to halt our education discussion. Right?

[LAUGHTER]

Because we're going to have a whole class, next week, on education. So we can pursue this at length. This is kind of a breath of what's to come, in next week's experiment.

But, Kevin, why don't you close out our ARPA-E discussion with-- maybe summarize what you thought some of the key points are about ARPA-E?

KEVIN: It's still growing. I think-- well, it might not be growing [LAUGH] anymore. But it's a good proof of concept that the DARPA model and models like it are good change agents, when they're needed. Especially in a really established legacy sector like energy is.

My personal opinion-- I'd like to see these kind of models applied elsewhere. You know, I was reading, here, that Homeland Security intelligence and others were planning their own ARPA models. And, even on smaller scales, I feel like this innovation model could be really beneficial.

WILLIAM BONVILLIAN: Good. OK.

STUDENT: I have one more question, because we were talking about innovation organizations. I was wondering if there was an innovation organization for manufacturing, because that's a focus of yours.

WILLIAM BONVILLIAN: There are these brand-new manufacturing institutes. And there's 14 of these. And they are organized around major technology challenges in the manufacturing space.

STUDENT: Could you specify?

WILLIAM BONVILLIAN: So, 3D printing. You know, what technology advances are we going to get out of that, whether it's-- there's an institute around tissue engineering and regenerative medicine. There's an institute around photonics. There's an institute around power electronics and wideband-gap semiconductors. There's an institute around advanced composites.

So, in 14 different interesting technology areas that could be quite powerful, across a range of manufacturing sectors, we are attempting an innovation model. It's a public-private collaboration.

STUDENT: So they try to do best practices in standardization?

WILLIAM Well, no, they're attempting to do technology development. So, TRA level-- TRL levels 4

BONVILLIAN: through 7, kind of, mid- to later-stage technology development efforts, tying that to the communities that would have to be involved if these models are going to get picked up. So it's an interesting-- it's the first attempt, really, in the US, other than SEMATECH, to bring an innovation model to the manufacturing sector.

STUDENT: Do these manufacturing institutes follow one general innovation model? Or does each one cater to whatever--

WILLIAM BONVILLIAN: Each one is-- they share a lot of similarities. They're all cost-share. They involve small and large firms. They involve university with strong technology and engineering programs. They involve community colleges. They have workforce-development model. So they share those pieces.

But then the particular technology area they're pursuing means they're going to be organized somewhat differently. So the one MIT is leading, on revolutionary fibers, that's got a different approach and a different kind of sector, frankly, than the composite sector. So it's an interesting attempt to bring innovation into a long-standing legacy sector where the federal innovation system never really played any role-- except for SEMATECH.

So let me turn to this kind of Plan B idea. The idea here was, you know, we're not going to do a cap-and-trade proposal anytime soon. So what do we do? You know, what's the menu of options, if we actually want to deal with climate change?

And one of the problems-- look, I was involved in drafting the original Senate climate-change legislation. And one of the problems in that legislation was, we were attempting an economy-wide fix, based upon a neoclassical economic concept that you could alter prices and drive change. And it turned out to be more complicated than that. Right?

First of all, it's hard to get an economy-wide model imposed. It's hard to nail everybody at the same time. Right? The political system tends to resist this.

In economic terms, it's very interesting to impose an economy-wide model, but it's hard. And then, secondly-- well, I had actually worked on the original acid-rain provisions the Clean Air Act of 1990, legislation to develop a cap-and-trade system there. It worked brilliantly, and it was a stalking horse for what we knew we were going to do on the climate layer.

And cap-and-trade worked brilliantly, there. It worked brilliantly, because we already had the technology solutions at hand. They could be the scrubbers that we were going to put on

smokestacks in Midwestern power plants. We knew the technology was there.

So a pricing system could really drive, very quickly, the forced adoption of that technology. When we did cap-and-trade, it took us a while to understand that a lot of the technologies were not close. They were still a considerable distance away.

We've talked about carbon capture and sequestration. It's a good example. Right? It's not ready for deployment at large scale, at this point. It's still experimental.

So it wasn't a great fit. So obviously the industries that were going to be affected by this, they didn't know what their pathways were going to be, in many cases. Right? And, look, in many sectors, look at transport. We don't know if it's going to be biofuels. We don't know if it's going to be electrics. We don't know if it's going to be hybrids.

We don't know what it's going to-- or maybe just significant improvements to internal combustion engines. All those pieces are still very much on the table, in the transport sector-- obviously a huge economic sector. So one of the problems with cap-and-trade and neoclassical model was that it didn't have a sophisticated understanding of the technology policy side. And I wish I had understood that then, but--

WOMAN: [LAUGH]

WILLIAM BONVILLIAN: --and obviously I wasn't the only actor. And, overall, I think a price solution is going to be needed, here. But meanwhile, can we make progress?

So part of the way in which we can make progress is by a considerably more sophisticated and effective technology strategy. After this book was-- after the book that this chapter appeared in was written, obviously there was a major political change in the United States. So the changes we're going to have to think about, if we're going to do a Plan B and I just sit on our hands for the next decade, I think that's a really important task. And we're going to have to think about who the actors are going to be that are prepared to take on climate change. Because we can't just afford to wipe off 4, 8, 10 years of progress. We've got to figure out what to do so.

There's a new menu of actors, here, that's potential-- at state level, and in regions, and in companies. Because I do think this innovation wave is under way. And Martín's point about niche players, that's an important economic point. You can move ahead with that kind of

approach, in a number of technology spots.

So, arguably, we're going to need a Plan B, and we're going to have to think about who the actors are going to be in Plan B. One thing which we did do in the Department of Energy, over the last 10 years, is make it a much more sophisticated technology-implementation organization, through work of Sam Bodman and Steve Chu and Ernie Moniz over the past decade. So all these new pieces, including ARPA-E, Energy Frontier Research Centers, to kind of turn the focus of the Office of Science onto new energy technology advances. There's 45 of these centers, now, at universities across the country. Office of Science is now really focused on new technology advances.

EERE, Energy Efficiency and Renewable Energy, has developed a major focus on advanced manufacturing as a way of driving down entry costs for new energy technologies. That's really important, if they're going to get in range of price. They've created something we'll talk about in the last reading. They have created a whole new way of getting, in effect, substituting space for capital, at the site of three historic energy laboratories. We'll talk about in the last reading.

They have a much stronger technology-transition office. They have innovation hubs that, when your technology is ready to kind of scale up, you can actually get a substantial amount of implementation and late-stage applied research money focused on areas like batteries, fourth-generation nuclear power, and a series of other technology areas.

So all these new innovation pieces have been added to the Department of Energy. So it's much more technology-ready than it was a decade ago. It's much more in position to be able to work on the energy tasks that it was assigned. So that's--

Obviously, these could be curtailed by the current administration. That's a genuine challenge, here. But at least we've got experience now with what some of these issues are.

There's still big gaps in the system. The front end is much better now, at the Department of Energy, but there's still big gaps-- areas like, how do you do test beds? How are we going to do a technology strategy that cuts across public and private sectors, for a common strategy across players? We haven't done that yet. We need new financing mechanisms for technology implementation.

So there's a lot of pieces that-- there still remain gaps on the back end of the system. But we have made progress. And, look, let me put the other piece on the table and we'll do them both.

Are both of these yours, Chris?

CHRIS: Yep.

WILLIAM BONVILLIAN: OK. So this is a chapter in a piece that just came out last month. The US is very reliant on entrepreneurial startups to bring innovation into its system. That's been a key innovation organizational accomplishment of the last 30 or 40 years, actually.

So we developed a $60-billion venture-capital support system to support startups. It's how we do it. It's a very interesting part of our system. No other country really has a system as strong as ours. The legacy sectors are like protected castles.

VCs don't like to take the castles on. You can understand why. They like to innovate in new frontier areas, where there are not incumbents, where they're not going to get opposition.

So, back in 2008, when it looked like energy prices were going to be high and cap-and-trade was coming along, VCs began to ramp up their investments in new energy technologies. And they've now walked. So let's look at venture-capital investment, nationwide.

This is what venture capital spent in 2015 its money on-- its $60 billion. Right? Software. Right? That's the long and short of it. They did a fair amount of biotech. Software was about 40%. That's about 13%. A bunch of services, media entertainment, IT services-- that was the bulk of the rest.

Now, you look at this little piece down here, right, this piece. That's 5%. That's hard technologies. That's energy and industrial. Right?

This has profound implications, absolutely profound implications. So the way in which we stand up new innovation is going to be through this venture-capital finance system. And all they're going to do is software and biotech and a few services.

We've got a serious problem on our hands. We're not going to have an energy-technology revolution. But we're also not standing up innovations in hard technologies. Software and biotech are not particularly job-creating areas. Software maybe negative job creating. Right? Are we going to have any jobs, in this economy? I mean, what's going to happen, here? These are really, really serious problems. OK?

We tried to do the same chart for 2016, but [LAUGH] the Venture Capital Association [LAUGH]

changed the way they collected their numbers, because software was so pervasive that they couldn't separate it out anymore [LAUGH]. Right? It was in every sector. So [LAUGH] 15 is the last good set of numbers we're going to get around software investment.

So, who comes to the rescue, here? So Rafael comes to the rescue. I didn't get this. I mean, this is his thinking.

And I had this conversation with him. We had been struggling with this, in the Advanced Manufacturing Partnership program, the President's advanced manufacturing innovation effort. How are we going to get financing for companies that are going to manufacture in the United States? Because they're not getting venture finance.

And we looked at the other potential sources-- you know, private equity, M&A in existing company financing. They're just not significant for innovative new companies. Venture capital is pretty much the story.

And, you know, Rafael-- I was thinking about, how could we do some kind of new financing, or how could we create incentives for venture capital to change all its rules and go after these harder problems? He basically said, venture capital is doing good stuff. Software and biotech are important things. They're going to do what they can do.

Substitute space for capital. That wasn't quite the way he put it, but that was the essence of what he was saying. And I said, Rafael, what are you talking about? Never had dawned on me. Right?

Basically what he said was, let's create really technology-equipment, know-how-rich spaces and get a bunch of very interesting hard-technology startups-- in other words, the biotechs are OK, and the software companies are OK. Let's get some of the rest of the crew in and create places where they get really advanced equipment and know-how. Right?

So there's a lot of technology incubators out there, and we've got probably eight of them right in our Boston neighborhood, here, and some of which are very strong. They tend to be earlier-stage. They tend to-- they capture you when you're new and you're really at the business-plan, business-development kind of stage.

There isn't really a model to help you, when you've got to start to scale up-- and with that scale-up proposition. So that's what his concept is. And it happens to speak, I think profoundly, to this energy-technology space, if we could create some of these. The engine that he's now

led the creation of is exactly an attempt to solve this problem.

In other words, his view is, we're leading a lot of science-based innovation developed in MIT, just sitting on the table. Because we don't have a scale-up mechanism. Can we work on trying to create a space where that could occur? So, in effect, what venture capital would finance-- that equipment, that technology, that know-how, for the scale-up-- can we contribute that, create that, and then invite the startups in that are doing hard-technology startups?

So there's a bunch of other models. DOE got this, big-time. ARPA-E began running into a wall. ARPA-E had assumed venture capital was the way in which its startups were going to work. And then they realized their startups weren't getting venture money, when venture-capital funding in energy collapsed-- right? Went down 80%.

So this band of characters took some space right at the Lawrence Berkeley Laboratory, up on top of the hill, up above the Berkeley campus, on Cyclotron Road. And they created a technology, equipment, know-how-rich space and provided salaries-- for a couple of years, which could be extended-- for a crew of startups. They're now in their third tranche. Very interesting. Very interesting companies. And it's a whole new technology transition model for the Department of Energy.

So, for possibly 40 years, the Department of Energy has been trying to get these big, famous energy laboratories that are on mesas, behind barbed wire, to transfer their technology out. And the folks that work there are paid, you know, guaranteed salaries for life. And they get entitlement-funded research. They're guaranteed interesting scientific work.

And we want them to walk out of there and, you know, not be paid in a stand-up company? I mean, good luck. Right? It's not an optimal technology transfer model.

And, look-- technology transfers with people that walk, right? Technology transfer doesn't happen by developing a list or a plan and handing it to someone. Technology transfer works through people. You've got to really encourage people to emigrate and move with the ideas, because they have the tacit knowledge to make these things happen.

Well, this may be a much better technology-transfer model for the Department of Energy than the one they've been working on for 40 years. So two other labs, Argon and Oak Ridge, have now picked up the same model. Steph?

STEPH: One of the elements I didn't see in the analysis of the models was the importance of competition or having that sort of truncated time frame. How is it that they sort of put pressure on them to deliver?

WILLIAM BONVILLIAN: Well all of these teams had to compete, to get in there. So that was a very tough composition-- more than 100 actors, 100 different teams, were competing to be part of the first eight. So that was a highly competitive process.

Look, if you've got an interesting startup idea and you're just out of grad school or, for that matter, just out of undergrad school, and you've got a really interesting, small group and idea and you want to move it, the fact that somebody would give you space, incredible equipment, and technology, incredible know-how, and pay you a salary for a couple of years, what could be better? Right? This is really good news, for hard-technology startups in the energy space.

So it's been very attractive, and there's a lot of competition to get into these places. So competition is embedded right at the heart of the model. Martha?

MARTHA: So, Bill, do you have any sense-- well, first of all, I can't remember how old they are and what kind of track record they have, at this point in--

WILLIAM BONVILLIAN: So these are all brand-new. This is a brand-new model. Right?

MARTHA: Cyclotron--

WILLIAM BONVILLIAN: So they just accepted their third round of teams. So they're two years old.

AUDIENCE: Got it. OK. I wasn't really clear. So are they going to be able to expand, under this new political climate, to other labs?

WILLIAM BONVILLIAN: We'll see. I think-- from the sense I have in talking to DOE friends-- what's wrong with this model? I mean, you're in effect repurposing an established model at extremely modest costs.

MARTHA: Right. So, in other words--

WILLIAM BONVILLIAN: Lawrence Berkeley Lab's an $800-million-a-year operation. You know, salaries, for these folks? That's not much. Right? And yet the opportunities of standing up with new technologies are really pretty significant, supporting entrepreneurs. So I think this one is a viable model, in

either political climate.

PERSON: Right, so who makes the decision? And what stage is the technology, when they enter?

WILLIAM BONVILLIAN: So, you know, this guy, Ilan Gur is right out of ARPA-E. So he's very used to-- he understands really well-- he came through a whole startup experience, himself. He's had startup experiences and has his PhD in science, from Berkeley-- very talented young technologist, very sharp, able guy. He's got a whole team, there, that's also quite able. And strong support from the lab. Right?

So the lab likes this. This is a way of getting their stuff out. Look-- it's a new model, right?

The model is, have a competition for, an effect, a nerd motorcycle gang. Park them outside the barbed wire. Give them a home, and give them the keys to go in and loot the place. I mean, that's essentially the model. Right? That's what they're doing.

PERSON: So, when you say "park them outside the fence," is that literal? Or--

STEPH: Yeah, that's literal.

WILLIAM BONVILLIAN: That's literal. They're immediately adjacent to these highly secure facilities.

PERSON: Why don't they just put them inside?

WOMAN: But allowed in.

WILLIAM BONVILLIAN: Well, they are allowed in. Yeah. Right. There are just some security issues, and--

STEPH: --side of a mountain, literally?

WILLIAM BONVILLIAN: Right.

STEPH: And it's quite steep. So, if you're walking and you trip, like, you would fall very [LAUGH] heavily.

WILLIAM BONVILLIAN: It's very beautiful. Great views.

STEPH: They have a great view the bay and the bridge.

WILLIAM BONVILLIAN: Remember, we talked about Ernest Lawrence? This is his lab. Right? Lawrence Berkeley Laboratory.

STUDENT: My only concern would be, if the technology's too early, they'll be based on, like, the people who they know, instead of the actual technology. So what would be interesting is if it's already technology that shows some promise, that way it's kind of like a pseudo right-before scale-up, where it's, I need to get my technical abilities scaled up?

WILLIAM BONVILLIAN: Yeah.

STUDENT: That'll be really good. But the issue is, like, this happens kind of like at MIT with, like, Delta-V, where it's like, it's kind of become a Sloane-y kind of like hub, where it's like, there's people who don't have great ideas, but they apply because they know the right person who does if they go through, versus, like--

WILLIAM BONVILLIAN: This is a very tough-minded selection process. You know? Ilan is a real talent. He's running a good process, here.

Look, we're kind of running out of time, here, so let me just get the rest of the story out. Because part of it, Martín, speaks to the next issue we've got, which is-- one of the issues here is, these are all early stage. Right? These are very talented technology teams, right out of university laboratories.

Here's a different model. TechBridge, right here in Boston, is part of the Boston Fraunhofer system. And they have a different model, but they're similarly providing this technology, equipment, know-how-rich space as a substitute for VC money. And the idea here is, Cyclotron Road starts with the technology group and then tries to nurture the technology.

TechBridge starts with large regional companies. And it goes to them, and it says, what do you want? Right? And, typically, they don't want disruptive stuff that's going to wreck their business model-- for obvious reasons. And they don't want to bother with stuff that they're already doing, that they understand well.

But there are substantial groups of adjacent energy technologies that fit with their model, that would be interesting to them. And that's what TechBridge tries to find out. So it gets a list of,

what do you folks want? And then it goes to find talented startups in the Boston area, of which there's a lot, and connect the right startup to the right industry player, for a collaborative project. OK?

Very different model. Very interesting. The most interesting part of it is that those folks work together for a little while. They come up with kind of the prototype together. Right? But industry doesn't quite trust the startup. The startup doesn't know whether it's going to get robbed by the big company. Who knows, right?

They bring in the Fraunhofer laboratories, this famous laboratory system, and the Fraunhofer labs do, for the startup-industry combo, what they do for German companies. They do a very tough-minded technology assessment. They break down the technology, they evaluate it--

Can this technology be manufactured? How would you manufacture it? Can you manufacture it at a price that would actually be saleable? You know, is this resilient technology? All the kind of stuff they do for German companies, they're doing for the startup. It's a very rich, sophisticated technology evaluation process.

We don't really have anything in our system like it, so it's pretty intriguing. And, in effect, they certify to the company-- I mean, they may say, this stuff is worthless, throw it away, or they could say, this is actually very interesting. Here's how you could make it, and here's the components you ought to use and the materials you ought to think about, and here's a pathway to a marketplace.

The company, the big company, loves this, because they realize the startup may not be totally crazy. And then the startup likes it because, in effect, it's certified their technology. So this puts both players into a much more informed space. And that's been very-- it's been very intriguing, sort of adding this technology-validation piece to this.

Remember, we talked about the role of FDA in certifying technology, which guarantees a market? This is the first time I've seen this played out in a US kind of model. And it's kind of intriguing.

And I'll put one more on the table for you. That's Greentown Labs, a respected, quite capable energy incubator, full of folks like you-- you know, off the lab bunch at a school, with cool energy technology ideas. Greentown began understanding that there are 60-odd teams, had a lot of neat research ideas. They had no idea to make anything. Right? No idea. You know, you

weren't taught how to make things, here at MIT. Although it is changing with the Maker movement. But--

University-lab-originated technology teams don't know anything about manufacturing. So they had an interesting idea. There's a manufacturing extension program. Every state has one, sponsored by the Department of Commerce NIST. Massachusetts happens to have a good-- quite a good manufacturing extension program.

Greentown and the MEP got together. And the MEP said, hmm, that's interesting. We've never worked with startups before. We work with small manufacturers. But maybe we could link small manufacturers and the startups.

And Massachusetts happens to have still a pretty strong base of small manufacturers. They work for the defense sector, the growing robotics sector, the medical-device sector-- which are big sectors, in Massachusetts, and there's some talented small companies.

The MEP ran a survey of its capable small manufacturers. And the survey results came back. 83 were interested in talking to startups. Why?

These small manufacturers are tied to existing supply chains. They don't innovate. They don't do R&E. They don't have access to innovation. How are they going to grow their market significantly? They're kind of locked into a pathway.

This is a route out, for some of them. In addition, others like the startup culture. They thought, that's pretty cool. Let's get my employees feeling like that. Right? Maybe we'll get some stuff done.

And some others thought, gee, the startup culture's important, now, in Massachusetts, to its feature acc-- [AUDIO OUT] We're good citizens. We're going to help them.

So they created this complex process of how to arrange these exchanges. Now, the startups, they communicate by internet things that you all understand and I have no idea. Of. Right? I don't what they are. But that's how they communicate.

You know, I'm exaggerating, here, but the startups by and large voted for Bernie, and the small manufacturers-- I'm exaggerating-- probably voted for Donald. And they worked by face-to-face meetings-- things like telephones. You know? You remember landlines? They still exist.

These are completely different cultures. How are they going to fall in love with each other and be able to trust each other to do technology development together? And there were no incentives, here. There were no subsidies. The startup had to come up with money, to fund the advanced prototype or the pilot production they wanted to undertake.

So there were no giveaways to incentivize people. This was real money, and both sides were at stake. So they arranged this four-step process, to try and bring about communication. 43 startups were interested. After a year of pilot projects, 19 deals. Money changed hands. Things were being made. Pretty interesting.

So this is another piece. We've now collected a bunch of ideas, here. Right? Bunch of ideas, here, that are potentially relevant--

From Cyclotron Road, repurposing an existing source of strong technology equipment and know-how, repurpose these energy labs. That's a really interesting idea, because that's fairly cheap. Right? You don't have to build all this new equipment. MIT is doing the same thing with equipment it's got, for the engine.

From TechBridge, the idea of, maybe you could do this-- maybe you could connect up companies at the outset, with startups. That's interesting. And maybe you could do a technology validation step.

And then this third piece, here-- and then I'll call it a day and let Chris lead some questions. But this third piece, here, is, maybe you could tie small manufacturers and startups, because they both have a problem that the other side could solve. Right? So you start to see a pretty interesting model for Rafael's idea of substituting space for venture funding.

This is an interesting model. Universities could do this model. MIT is trying to experiment to show other schools that it could be done.

Federal labs are already pursuing this. And the DOD has 67 of these, and Lincoln Lab is extremely interested in this model, for example. So is Draper, just up the street.

So, in other words, there are ways this thing could scale. Right? So, between universities and existing laboratory capabilities-- and then MIT's got the idea of connecting you to companies and nodes that could help you as you develop a more sophisticated product line.

So there could be a new model, here, that would really help with what's become now a very significant gap in US innovation system, over the collapse of venture-capital funding for other than software, biotech, and certain service sectors. Chris, it's all yours.

CHRIS: Awesome. So I thought this is a really interesting article, because you often hear about, oh, energy, funding, and the whole system's not really working, but it was kind of hard for me, at least, to see why, and, like, the discussion of the neoclassical economic model and why that doesn't really work out, especially for this kind of industry, was pretty interesting to me. So the way I saw it was that--

So there's kind of a twofold problem. Like, we have problems in energy revolution and the technology space and then also, like, implementing those technologies. And Reif presents this innovation-orchards kind of framework, which is really interesting. And, as Bill mentioned, we have a somewhat robust kind of model for early, maybe like incubator-type startups. And then we have to somehow bridge that gap to innovation.

I was just wondering, what are your thoughts on how we can kind of create that smooth transition between institutions that might be providing some early seed funding and then how to transition those into later stage, whether those be connected to, like, TechBridge or those other models that have kind of demonstrated some pretty good ways to bring that implementation process into play.

RASHID: I think two things. One, I was pretty astonished at the first piece, particularly taking this neoclassical view of, hey, should we do cap-and-trade instead of carbon tax [INAUDIBLE] for curbing emissions? And I think it did a pretty good job of saying that maybe, like, it's more complicated than that, but also like the fact that we were still looking to do sort of a cap-and-trade system, even in 2010, which is relatively recent, and classical economics has existed for a while now-- made me think, like, is economics--

Are the solutions that we think theoretically, like, in economics, are they effectual? And are they just kind of limiting us, because we only have this school of economic thought that says this is sort of our solution subset, this is the answer? And are there economists out there aren't neoclassical economists, that may have solutions for us that exist outside of-- that probably would be a lot more palatable and useful than a carbon tax or a cap-and-trade system.

WILLIAM BONVILLIAN: So, Rasheed, let me build on that for a second and just-- and, just to be clear, don't get me wrong, I do think a pricing mechan-- there is definitely a place for a pricing mechanism. It can

help a lot.

I think part of the problem, here, is that neoclassical economics, as we talked about in the first class, hasn't been able to develop an outlook that enables it to treat technology innovation as endogenous to economic-growth theory. Right? So SOLO announces it's exogenous, because it's too complex a model for us to track the variables. And, as we've talked about in this class, it involves history and culture and organization theory and all kinds of other things that are kind of outside the parameters of what economics is normally able to track in its curves.

So that's a genuine problem. So when neoclassical economics comes up with a fix to climate, it misses the technology side. Because it doesn't have sophisticated handles to deal with it. Now, obviously economists like Romer and others are attempting to make technology theory endogenous, part of economic theory, but that's still an ongoing project.

But that's where we ran into trouble, was that the technology need over an extended period of time didn't match the timetable on cap-and-trade. And the solution there was to push off cap-and-trade. And that's, in effect, what we've done. I still think we need to come back to it, but I think the project at hand is a technology-development project and really a state and local government technology-implementation alternatives, where we could come up with a Plan B that helped make progress for the next decade or so.

STEPH: I also, to add to Rasheed's point, I think that's what I was getting at last week, with my point about nonmarket solutions to market-- to problems that we're approaching through the lens of economics, in the sense that, perhaps if we think about-- if we start our problem-solving from a lens of promoting social good, rather than increasing capital gain, then we might be able to come up with alternative and innovative solutions. Right? And so I think that's sort of where-- Reif?

STUDENT: Reif.

STEPH: Reif was coming from, that this model-- and I mentioned this on our very first day of class-- very much is similar to the model that nongovernmental organizations and nonprofits have been using for a very long time, in sort of trading or leveraging the kindness of individuals and their willingness to let them participate in their spaces. And you see this happen for political campaigns. Volunteer fellows will go, and they will live in a supporter's house, and then they will go on and knock on people's doors for that candidate. And they will do so for very little money or no money at all.

And so, as someone who comes from the nonprofit and NGO sector, and I've been you know volunteering in politics since I was really little, the ways in which you can leverage on the sort of good and ethics of people seems to me a much more interesting place to start for research and development and for hardware technologies than people would think. Because, if you approach it from a lens of economics, it's very difficult to make the case, oftentimes, that your technology could be disruptive and could pay off. But if you approach it from a lens of social good, it's possible that you could appeal to the ethos of a venture capitalist. Because, for example, someone like Bill Gates is more likely to say, I want to do this because I think it's the right thing to do, than to make the argument that it's a good investment for him and that the ROI will be greater.

So I think that there is a benefit to sometimes pivoting away from market-oriented problem-solving and to view it from a different sort of lens of ethics or social-good promotion. Obviously that won't always work, but there are instances, and I think this is one, in which that is where we are leaning toward.

WILLIAM BONVILLIAN: And I will add, Steph, to your point, that part of what has come with the engine is a bridge fund available to those startups. So Rafael and colleagues have been able to raise over, I think, $150 million, now, for commitments to a bridge fund. Because, you know, these startups are going to need some funding. Right? It's not going to-- they save huge expenses by equipment and technology and know-how savings, in this new space, but they still are going to need to get funding. And so this bridge fund could really help them.

That money was raised from, essentially, generous rich people in this region, who were prepared to, in effect, make a charitable donation towards this thing, thinking that it might be helpful to the overall innovation economy in the Massachusetts area. And they have an opportunity for return. So, if these startups take off, there is an opportunity for return. But, frankly, they're not expecting it.

So that has actually worked. And Rafael has just been able to demonstrate that you can raise money on the basis of that kind of approach.

STEPH: And I think they're one of the interesting models. And perhaps you've looked at this. Maybe you haven't. But it's the way in which art museums and, in particular, contemporary art museums pursue funding from philanthropists. Because it's often that a lot of the

contemporary artists that are sort of on the leading edge are something that people are very reticent to adopt. So the museums that purchase their art, either for their permanent collections or for their temporary exhibits, often allow their philanthropists to gain some sort of benefit or value from having hosted that and having attached their name to it. And, later on, it is that, because art is seen as a commodity and luxury good, they're able to sort of gain capital return on it, as well. So I think it could be interesting to look at the ways in which museums and art museums specifically do their philanthropy for technology.

CHRIS: Sure. Go ahead.

STUDENT: Well, I think there's-- OK. There is also, like, purely private-sector market-driven models. I think a really good example is Autodesk., so right down here by the seaport. And--

WILLIAM BONVILLIAN: Why don't you describe it.

STUDENT: Yeah. So, Autodesk, they basically want to become the software company for any CAD, CNC, anything that you want to make. And so they have a fellowship program here, and then-- so Auto-- they're MIT startups who work in their build space at the innovation building. And they also-- like, Pier 9 is, like, probably the best maker space in the world. And they have [INAUDIBLE] come in.

For them, they get a lot of value out of it, because these innovators are testing their software and pushing it to its limits and giving them ideas for new features. Also, when those startups hit market, Autodesk really helped make that possible. So there's a lot of benefit to them. And they give these people working on hard technologies a really great working space to develop their stuff.

WILLIAM BONVILLIAN: Chris, do you want to give us a few closing thoughts on this?

CHRIS: Yeah, sure.

WILLIAM BONVILLIAN: You had some very perceptive opening comments.

CHRIS: Cool. Yeah. So, I think one thing we didn't really get a chance to touch on was that climate change and, like, the whole energy sector is kind of a different beast from a lot of different kind

of sectors, because the way you evaluate how "good" a technology is, is kind of a much longer time span than, say, I don't know, biotech, where you can immediately see the impacts. I mean, the drug works or not. Right? You can immediately tell.

But, for climate change, sure, you can, I don't know, measure carbon emissions year by year or something like that. But then you run the risk of, policies, social mindset, or whatever, shifting, once maybe you get on a trend of seeing some improvement, and then you might just shift and completely erase what you've done in the past year or so. So, definitely, the longer time span makes it more difficult, not only for funding but also, like, development, implementation. And I think a lot of these new models, like the innovation orchards, TechBridge, these models are really cool and should be interesting to see how they play out.

WILLIAM BONVILLIAN: Great. Martha, do you want to give us a thought from MITI's perspective about some of these new models?

MARTHA: So-- well, I guess that-- Bill, you kind of caught me by surprise. I've been holding back--

WILLIAM BONVILLIAN: Sorry.

MARTHA: That's OK! That's all right. I think-- well, first of all, Chris just touched on something really important, which is that one of the big challenges-- and I think I've mentioned this before-- is that, traditionally, energy technologies take decades to get adopted. And just the pie chart on the VCs [LAUGH] tells you something about what energy technologies are competing against for capital. I guess that this is a great model, if it could get replicated, you know, and even break through energy ventures, which is a different model. I mean, this is an earlier stage, helping people get past.

It feels like things move slowly. And, like everything related to this whole energy challenge, we need to kind of pick up the pace. And, Bill, you talked about the states and that there's different players. It's challenging. Right? I mean, the states just don't have the kind of-- first of all, they compete against each other. They also just don't have the resources. So we'll see where we end up.