WILLIAM BONVILLIAN: Let me quick do a wrap-up of where we are, just so you remember our context. Class one was really all about growth. Economics, as you all know, when we talked about the contributions that Solow and Romer made, and they really forced us to look at what we could call two direct innovation factors. What Solow called technological-related innovation we can sort of translate that as R&D. And Romer, the talent base human capital engagement research was his key term. We read Dale Jorgensen, and Jorgensen showed us that technology-based innovation really was the driving causative factor in the great growth spurt of the 1990s. That was the innovation wave around the IT revolution, as you remember. And we talked about how there were direct innovation factors. So Romer contributed those, arguably, and others. But there are also many indirect factors. All right? So less critical factors, but this is a complex ecosystem of innovation.

Richard Nelson gives us a third innovation factor, looking at innovation as a system and the organizational elements within it and the connectedness of the different actors and the strength of the different actors, so that gives us a systems' way of evaluating an innovation system, whether it's national or regional or local. Nelson gives us a perspective on how to look at that system. Atkinson and others contributed on innovation wave theory. The way in which economies grow is that they bring these new innovation waves on and scale them up over an extended period of time. They start very gradually, finally reach a point where they can scale quickly. There's always a bust, then they scale more gradually. That's kind of the stages we've talked about. We're now with the IT revolution.

Charles Schulz taught us to kind of be aware of industrial policy. And we talked a lot about the government role here, but that's a cautionary tale of some problematic aspects of a governmental role. Classes 3 and 4 were really about advanced manufacturing, which we did as our first big case study. Obviously we'll have another big case study today. We had health last week. Class 5 was on innovation organization, and we talked about the different models that kind of govern the ideology of innovation in this country. The associationalist model, which we could call the public-private partnership kind of model. The conservative model, which is governmental intervention. Government should stay away from intervention, including into the innovation system except at the most basic kind of levels versus a national security model which justifies intervention at any stage if the need is related to national security. And these debates go on. There's a couple of other models, but those are the ones that really represent the core debates that still go on.

We talked about the importance of looking at innovation from both the institutional and the personal level. So people innovate, institutions don't. You need to understand how the institutions interact. But in the end, people own particular innovations and bring them about. So you've got to understand innovation at that personal level, as well. We talked about Donald Stokes and a core issue in the US system, its disconnected model. The fact that we tend to focus on early stage research and have less focus on the implementation stages further along. And that creates a significant tech transition problem in the US system.

Class 6 was about that how to get across this, quote, "Valley of Death," which has been the major policy preoccupation of US science and technology policy for the last say 25 years. And in contrast we read Vernon Ruttan, another growth economist, who taught us that, by the way, there's a whole parallel system out there, there's a parallel universe in the way in which the US R&D systems are organized. There's a highly connected defense information system that's very different than the somewhat disconnected civilian side R&D system. Class 7 was great group theory, what does innovation look like at the face to face level? Innovation, again, is people, it's not institutions. And what are the rules sets that tend to govern the way in which teams and groups of people working on complex innovations. How they come together? How do they assemble? How do they organize? What are their rules? So that's all about a third direct innovation factor, innovation organization, at both face to face and institutional levels.

Class 8 was around DARPA as a very different kind of model that attempts to do both a connected model and innovation through a connected model at the institutional level, but it also operates in creating great groups in a very conscious kind of way. And we explored the whole idea-- revolution role that DARPA played. Class 9 last week was really about the challenges in the health innovation system. It's a early stage research, basic research focused system.

It's a quite disconnected model, big organizational challenges through the 27 different institutes and centers at the National Institutes of Health. Getting cross-cutting science going between those institutes is hard. Yet we're now at a stage where a new revolution is coming along, which some termed the convergence revolution. That's going to mandate much more cross-cutting science, and yet we've got an institutional organizational problem that's not adapted to handling the kind of next generation breakthrough territories.

And now, energy. So we're going to really bring to bear here the legacy sector analysis model that we've been touching on at several points. But today it really comes into focus. Obviously, we touched on it last week in the context of the NIH, but it really comes to bear here. And the issue of innovating in complex established sectors is a big problem for the US. It's a problem for everybody, it's a particular problem here. If we can get around and tackle this problem we could address a lot of issues.

Since 80% of the economy is in these legacy sectors, we limit our growth rate by essentially doing a new frontier kind of innovation model of looking at standing up the next big thing, we lose track of what we've done in the past, we tend to focus our innovation on standing up new territories. That affects our growth rate, right? So the whole IT sector in the United States, as huge as it is, is still measured as only about 4.6% of the US economy. That includes copper wire telephones and hard bound books, too, right? In that information technology sector.

It's a challenging issue of how to bring innovation of the sectors. If we could figure out a better way to do it, if innovation is the dominant causative factor of growth, then we start to think about affecting our growth rate in a new kind of way. So that's why this case study, I think, is particularly significant, not only for energy itself, which is obviously very important, but for its implications of how do we innovate in legacy sectors.

So we'll start with Socolow and Pacala. And who's got Socolow and Pacala? Matthew? All right. I'll just briefly summarize their work. As you know, both Princeton experts, they helped give us a conceptual framework for thinking about the challenge coming up in energy technology. And the community have been doing a lot of fairly sloppy thinking about-- everybody had their favorite silver bullet that was going to solve all problems, right?

And Socolow and Pacala got us thinking that, gee, there's not going to be a single silver bullet, there's going to be a whole series of things that need to be undertaken if we're going to tackle the energy technology challenge. And so they developed something which is now widely known as wedges theory. And when they were writing-- if we just stabilized CO2 and greenhouse gases, at the time they were writing, that would have been enough. We now know that we've got to go much more deeply. So it complicates this wedges story significantly. But when they were writing, as you can see, their assumption was that would be the growth curve of greenhouse gases and we could simply stabilize it by introducing these wedges, that could tackle the problem.

When they put this out in 2004, it really gave everyone a new kind of picture, a new kind of intellectual framework to help think about this big energy problem. They picked 15 different energy initiatives, they argued that if you did any seven of them you could grow them in a reasonable time frame into-- that multi decade time frame into large enough wedges of energy supply that you could bring emissions down over a five-decade period to a stabilized 2005. So we now we've got an 80% reduction, not just stabilization. But the concept is still with us.

Now, some of these wedges were clearly within the range of adoption, and with a concerted effort they could be scaled up in a timely kind of way. Others were just plain really hard to even think about implementing. For example, they called for massive deforestation. A big challenge in countries where that would need to occur. They called for a 50% reduction in driving by 2 billion vehicles. Yeah. Good luck. You know, massive adoption of conservation tillage. I mean, all these are conceivable, right? But some are harder than others. And they take not only changes in government to write to policy and technology advance, they require very significant behavioral challenges, which is particularly difficult to impose. And others, like carbon capture and sequestration technology, are still, to this day, a considerable time period away from practical implementation. We don't have the right technologies yet. And then there's a whole period of development and demonstration that really needs to be ongoing before we can really implement those approaches. We just don't know what the best practices are, particularly in the sequestration side.

So that's some of the challenges here. Interestingly, Socolow and Pacala's work got taken up by the contending communities battling over climate change at that time. So Socolow and Pacala, again, they're only battling for a 50% reduction-- I mean, excuse me, they're battling for stabilization, not a 50% or 80% reduction. They argued that we could get their wedges without doing a lot of breakthrough work, right? That the solutions were at hand. So the environmental community was facing a big battle with industry. And the industry was saying, sure, we'll do climate change, see in 20 years we're going to do some R&D and we should have it done within at least 20-year period, no problem.

So that was obviously unacceptable to the environmental community. They used Socolow and Pacala to argue, wait a minute, we don't need to do these fundamental breakthroughs, the solutions are at hand. So in effect it pulled both sides off of technology development, right? In a period of time where we actually really needed to do a lot of technology development because I would argue with you that if we're going to get to the levels of CO2 reductions that we need to reach, there is a lot of technology advance that needs to go on. And this kind of pulled the debate out of that. It's not their fault, that's not what they intended at all, but it created a kind of positive agenda for the environmental committee that I think in the end was misleading to them as well as to others. So that was the dilemma in what they proposed, but nonetheless this wedges concept presents a picture of how we're going to go after this problem. That remains extremely important. Matt, it's all yours.

MATT: Well, the first thing I wanted to talk about was Socolow and Pacala seem to be writing to the world. They talk about global emissions. And here they are publishing in Scientific American to popular science readers in the US. I think a few people also caught on this. Somewhere in the article they mentioned that richer economies tend to become less energy-dependent because you're not making steel or doing these highly energy-intensive activities. So I think it's important to talk about whose responsibility is it to pick up these wedges, and is there a way to optimize it so that we don't keep developing economies from developing in the process.

AUDIENCE: Actually, I kind of disagree at least with the notion that the more developed economies don't use energy as much because-- or at least that they don't pollute as much, because at least the United States, they pollute-- what is it? The second most in the world?

WILLIAM BONVILLIAN: Yes.

AUDIENCE: Yeah. We have like 25% of the world's pollution, it's just here, even though we're extremely developed. So I don't know if we can put a lot of the blame on developing countries. It's really the pot calling the kettle black there.

MATT: On the other hand, I guess pollution is something we can manage and reduce without having that take as much of a toll on our economy as in developing countries to start producing steel, right?

AUDIENCE: Well, we haven't done that yet.

AUDIENCE: I think that's interesting. I think there's the potential for more developed countries to take a smarter approach to how they manufacture, but I really like that sentence. It really shook me up because almost it's like it implied the wealthier that you get as a country the less you need to manufacture produce. I don't know if I'm really misunderstanding what that point was, but--

AUDIENCE: I think the point that you're referencing is on page 56 of this report. And they talk about how energy or how manufacturers are increasingly improving their energy efficiency. They don't necessarily say that the impetus is no longer on the developing world or that richer countries have to take on energy reductions, but specifically that energy efficiency is improving, and thus there is hope at least in developed countries to take up some of that, I guess an increase in the developing world in manufacturing, specifically.

AUDIENCE: I think the point that they're referencing specifically was a bit earlier when they say that heavy industries like steel and manufacturing tend to move out of the more developed countries to less developed countries. And my whole confusion with that was that it seems like they're saying that that was going to reduce emissions, which, yes, it will reduce the emissions in the US and developed countries, but it's just like moving them to a new place. So I was confused as to why that is something that they're commenting on at all in this discussion because it's just moving emissions around, it's not changing them.

To the front page 52. Yeah. Sorry. That's on page 52, right? Two long-term trends are surely improving--

WILLIAM BONVILLIAN: I'm really impressed, Steph. That's--

[LAUGHTER]

AUDIENCE: First, as societies get richer, the services sector grows in importance relative to energy-intensive activities such as steel production. So second deeply ingrained in the pattern of technology evolution is the substitution of cleverness for energy, which is their point about energy efficiency.

WILLIAM BONVILLIAN: Yeah. And as we know from the manufacturing case study earlier this semester, that turned out to be a problematic view, largely from economists about the nature and importance of significant production systems in developed economies, as well as less developed economies. But it is a widespread set of assumptions that economists were pressing at the time that as though there was a natural evolution that an economy would naturally evolve into more service sector activities and forego the need for a production cycle. The problem was that that evolution, which certainly took place the United States, did not necessarily forego the need for a strong production sector as well, as we discussed back in classes four and five, because it turns out that the production sector is so deeply tied to your innovation system itself. Sorry for the recap.

MATT: Well, yeah. I was actually on other question-- I think Sophia asked it-- was, now that kind of thinking about this changing, and maybe we don't want just services focused by sector or industry, and we bring back manufacturing, does that mess up kind of what Socolow and Pacala are presenting here, where that's something-- in their model, that's something that will help us in the long run.

AUDIENCE: Can you say that again?

MATT: Yeah. So Socolow and Pacala are saying, as countries become more developed than the average economy. They kind of move towards this service-heavy economy. And that in the long run helps decrease or ease that country's carbon emissions. But now that we've been rethinking it and saying manufacturing is something we want back here in the United States, that paradigm changes. And how much does that disturb the presentation of this wedge theory.

AUDIENCE: So, actually, I kind of a question about how emissions from the United States decreased in the past 30 years? If so, by how much?

WILLIAM BONVILLIAN: We actually have been decreasing emissions, particularly the last seven years in a fairly significant rate. And, again, more analysis needs to be done. Martha, you probably have insights.

AUDIENCE: Well, the only insight they have is because of the natural gas boom is one of the big reasons we've been reducing emissions, not because of less consumption or-- I mean, there's some energy efficiency, but a lot of it has to do with gas being cleaner than coal.

WILLIAM BONVILLIAN: Right. So we've gone through a whole technology revolution led by fracking. And then, another factor here is that frankly the US has been de-industrializing, right? So when we reduce manufacturing employment by 1/3, that turns out not to have been primarily productivity gains. That turns out to be a real hollowing out of that sector. So we shut down 60,000 factories, as we talked about in class four, between 2000 and 2010. So to some extent, these are unintended consequences of some problematic developments in our economy. But the big one, I think, Martha's put us on to is the fracking revolution.

AUDIENCE: Also, when we do that measurement, is it based on the emissions per production or are results take into account, like how much emissions you do by creating the products? So I'm thinking solar panels-- what would be the emissions to create solar panels and produce them? Because that would affect the measurement.

AUDIENCE: Yeah. So I don't know the answer to that. I'm guessing it doesn't include what goes into the solar panels or the wind turbines.

WILLIAM BONVILLIAN: Right. And that's a tricky process. What is the net emissions of a new technology, including its own production and installation systems? Making those estimates is not simple. How about one more question, Matt?

MATT: All right. Another question. Generally, what do people think about the seven wedges theory? So I saw some people had questions about it and I did too in terms of, yeah, some of the wedges seemed really hard, but some of the wedges seem manageable on their own. But once you start putting all of them together, even just from a financial perspective, it becomes marginally more difficult to take that next wedge. And they don't actually seem exclusive. So if you look at power generation, you raise the efficiency at 1,600 large coal fired plants from 40% to 60%, then another one is replaced 1,400 large coal fired plants with gas fired plants. And does trying to do one wedge cause another wedge to shrink? And then you're looking at adding up a lot more. I thought it was helpful, for a popular science magazine I thought was a helpful framework, but I was wondering if there were some shortcomings that people had issues with.

AUDIENCE: I was a little surprised by how fossil fuel focused it was. Still one of the big solutions was carbon capture. And like you said, one of the options is to keep using coal, but to just make it more efficient. So, I mean, I understand the reality that we probably will be reliant on fossil fuels for a while, but I thought that this is an interesting approach to continue in such a way.

WILLIAM BONVILLIAN: Martha, I know you've thought about that question.

AUDIENCE: Well, I guess maybe only thought I'm having is, will the carbon capture and storage has totally not panned out yet to be anything close to economic. So it is a little fanciful, a piece of it.

WILLIAM Right. On the other hand, the possibilities that a purely renewables approach.

BONVILLIAN:

AUDIENCE: I see.

WILLIAM BONVILLIAN: Is going to be doable. You know. I think that's problematic as well.

AUDIENCE: Right, absolutely.

WILLIAM BONVILLIAN: Because these are not baseload power systems.

AUDIENCE: For me, I found the most problematic pieces to be kind of-- as we're commenting, it did seem sort of arbitrary, but in addition to just sort of just kind of picking whatever, the ones that they picked, it came down to, I don't know if I would necessarily kind of start if I was saying that these are the 15 that are going to be the most feasible ways to get us on these wedges. And I'm particularly looking at stop all deforestation.

AUDIENCE: Yeah.

AUDIENCE: Yeah. I don't know if I might need some more reading in deforestation, but that seems to me like a variable really interconnected kind of big issue there. And I feel like there's a lot more, and agriculture and forestry could have picked before kind of blanket with just saying stop all deforestation. And yeah. So I think within each sector there could probably be a more meticulous approach to kind of make them exclusive, so you don't have this sort of overlapping power generation between coal fired plants and things like that. That was my main issue with the wedges.

AUDIENCE: I thought it was a very academic paper. I think it's a really good lens to look at the problem. But in terms of practicality, I don't think it would be practical. It seems like it's kind of idealized, like outside reality. The approach I would take with this paper is to look at their assumptions and then go out into the market and talk to factories and people who are using these technologies and figure out how they think about these things, because they might just be like, that's not going to happen. So I think it's a good lens, but I wouldn't-- I don't see it as practical.

AUDIENCE: I just looked it up. Robert Socolow actually wrote a follow-up article in 2011 called *Wedges Reaffirmed* in *Climate Central* to talk about the reception not only from the general public, but also from the scientific community, from the policy making community. And he seems to sort of be of the opinion that he-- they not only overshot the science of carbon capture, but also really we're trying to pander to the quote-unquote "general American" and we're not as sort of hard-hitting with these solutions that they could have proposed in the magazine article.

And in particular talked about how people commented on the concessions that they made leading to benign outcomes on fossil fuels, as you were saying, and that they would foster complacency. And he says that he doesn't understand that fear because when he tells someone that we could be lucky to figure out the technology, then the listener completes a sentence and says, or we could be unlucky. So he seems to say that we're kind of between a rock and a hard place on trying to convince people to create a framework for energy reduction while also sort of maintaining our standard of living and also caring about the environment. So he seems to have gotten a lot of backlash that he reflected on for some time.

WILLIAM BONVILLIAN: Right. Both of these folks are very shrewd, talented people and very perceptive. And part of the story here was what we thought was the case in 2004 and 2005, which is just stabilization at 2005 levels would do it if we've got to get a much deeper set of reductions in the place.

AUDIENCE: I think even when they wrote this they suggested that in the long term we need to bring it down.

WILLIAM BONVILLIAN: Yeah. All right they were aimed at a 50 year period. They recognized that in that later period there would really have to be breakthroughs. But they avoided the breakthrough problem in the 50 year period, but it's now on us. Right? We're going to have to have a level of technology advance that was passed what they were-- and what policymakers in general were thinking about that time. That's a good closing thought, Matt. Anything else to add on them?

MATT: Yeah. I think it's generally a good-- I thought it was a good first article just that way, but like Bush's innovation pipeline, there's a lot more complexity in the test that we need to work through.

WILLIAM BONVILLIAN: That's a good comparison. Thanks, Matt.

All right. So we're now going to dive into-- Chuck Weiss and I affected a whole book on this. This is just a kind of snapshot, but the idea we tried to get across here is that challenge is big enough that we're going to have to get inside the kind of black box of innovation, innovation policy, innovation proposition. So there'd been a lot of articles around the time we worked on this, 2009 timetable. And a lot of major studies, and the studies always said, and we're going to need some technology advances, let's do a lot of R&D, right? And that's kind of as far as they went. And what we were attempting to do in the book, as well as pieces that came out of it, like what I had you all read, was really dig into how that innovation system worked and understand it in a more coherent and real kind of way, getting us in there to that black box of innovation policy and figure out what could be done.

Just as a few background points, historically, the government has been much more interventionist in the energy sector than most other sectors, right? Government is historically very interventionist in the health sector, it's been very interventionist in the energy sector as well. And the political parties tend to have their favorite technologies, which complicates the political agenda here for a technology agenda.

It will complicate it for the next several years for sure. We're already seeing some of those slides. And then there's another reality here, which is we don't have a lot of the technologies we need at hand yet. There's still a very significant technology development effort that needs to go on and a series of these really important strands. We can see what the pathways are, but a lot of the technologies we're going to need are still not technology ready, much less being economically ready, where it's ready for market adoption. So that complicates this challenge very significant.

Energy is scale, right? It is a gigantic sector. And you can't consider energy policy unless you're considering scale. There is a technological, economic, political, social paradigm that creates barriers to change in the energy sector that are quite significant. Private sector R&D, and obviously this is private sector technology. The government is not in control of this technology to say the least. Private sector R&D is discouraged by wild price oscillations in energy markets. We'll look at some of those in just a minute. $20 a barrel in 1998, $140 a barrel in 2008, $35 a barrel in 2016. It's very hard to do R&D against those kinds of price disruptions. The public sector has been working on energy R&D and comparatively few technologies have transitioned. Again, fracking frankly is the major technology development that really has transitioned.

And you've got to think about parallel and supporting policies, not only on technology, but also on price. Right? So it's technology, supply, but that's dramatically affected by pricing. So very large in scale and scope. The problem of energy, as I said before, really is the problem of scale. You can think about a large scale kind of activity, like an Apollo type project for pursuing this, but you would not have an Apollo type project that's government contract-led, right? We're not going to solve this except in the private sector, which makes the effort considerably more complicated. And as Socolow and Pacala suggested to us in the reading we just discussed, this is a 50 year project.

So the United States has never done a 50 year technology project. We're lucky if we do three year technology projects these days. Apollo was a nine year project, right? That's about as long as we can stand, much less a multi-decade problem. And then, with a multi-decade problem, we run the problem of locking in prematurely to wrong technologies. So that's the fundamental problem with corn-based ethanol, which 1970s already felt like, great, corn-based ethanol, what could be better? Farmers get rich, they grow our energy for us, how nice. But it turned out to be not as significant emissions reduction, if anything, maybe the opposite.

So locking in. We're now every bit as addicted to corn as we are to oil, and locking in prematurely on a technology is a big problem. How do you maintain a certain amount of technology neutrality over a 40 year period? We have never tried anything as complicated as that before. And arguably, you need to organize around barriers to market launch, not just throw R&D money at the problem. So we'll get into all of that. But energy arguably requires a new unified theory of innovation because it is such a complex project. You can't just do a pipeline model, you can't just do in an induced innovation model, you can't just do a manufacturing led innovation model. You've got to think much more deeply about how you bring all these models to bear using an innovation organization approach. It's kind of no way of getting out of that box in the energy sector.

AUDIENCE: Is there a paper that's looking to pass energy revolutions and figure out like the main kind of pushers?

WILLIAM BONVILLIAN: Well, we went on too many, right? So I don't know how many million years it took, but we did wood fire. We did that. That was big. Then, from wood we did coal. And [INAUDIBLE] tells the story that William Barton Rogers, the esteemed first president, and frankly, genius behind the MIT model, he died on the podium during an MIT graduation choking on the terms by [INAUDIBLE] coal revolution, right? So that was the big revolution in that era. We moved from wood the coal. So that's how slow it is. In a remarkably quick period of time, you know 60, 70 years, we actually moved to oil. Right? That was remarkably quick. And you know we've been on that fossil fuel revolution ever since. And it's not easy to shift, so these are very long-term projects. And you really have to think about time and scale over and over again when we think about undertaking energy technology change.

So we talked about some of the models previously just to remind you we know the pipeline model well. For sure there is going to be a profound need here for breakthrough research. There is a big valley of death problem in that pipeline model that we've got to think very hard about. But that's not the only problem, we've got induced innovation here. In other words, industry is going they have to take responsibility for a lot of these particularly incremental advances. But how do you encourage that when the industry is locked into a set of technologies that you want to mitigate? That really complicates the induced innovation model. Well, it was in the article.

Chuck and I've been thinking since then because from the book there's an extended pipeline model, the whole defense sector model where the government engages not just at the upfront stages, but the later stages through implementation as well. What can we use in that model? And that's a Defense Department-owned model by and large. And we'll talk later when we talk about the Dorothy Rubin reading about whether that's applied. Manufacturing led. In other words, we're not going to have carbon pricing for a significant period of time. So unless you drive the price down, these technologies will never enter. So the way you drive price down is through manufacturing advances and process advances and that becomes very much part of what you've got to consider in an energy innovation model as well.

So innovation organization. How do you put these complex pieces together for a new model is really at the core of this. So just to summarize so far, it's a problem of scale, we're up against a technological, economic, political, social paradigm-- we'll talk about that in a minute-- in a very complex established legacy sector. And maintaining technology neutrality over a 50 year period, a really critical problem, which needs a tremendous amount of thought and organizing.

And then we've got to undertake the integration of the different models by which the dynamics of innovation get played out, right? You can't just do pipeline here, you can't just do extended pipeline. You've got to really bring all of these to bear because they're all part of that solution. So innovation organization becomes central here to an energy technology revolution.

Let's look at investments in energy. So US federal R&D spending on new energy technology when we wrote this piece was about half of what it was in actual dollars because it was in 1980. So the blue is public sector investment. You can see the high watermark about 1980, and it's come down since then.

The gray line is private sector investment levels. You can, again, see that that's basically through this 2005 time period and it hasn't gotten much better since. That basically fell in half, as well, right? So this is not the picture you want to have if you're going to do a technology revolution, all right? Let's look at the way in which innovating industries, how do they spend when they're trying to do major technology implementations? The semiconductor industry invests 16% on average of annual revenues in R&D.

And they've got to stay on Moore's Law. Moore's Law may have just ended, but that was a long term project for them and they had to keep investing in R&D to do it. The pharmaceutical sector invests 18% because their drug terms keep running out. They've got to stay on top of the R&D side. The biotech sector invests 39%. That may be a little unfair comparison because a lot of the biotech industry has no revenues at all, so it may skew the numbers a bit. But the other two are probably pretty good signals.

Established industry. The electronics industry, 8% of sales. The auto industry, at least before the great recession, was around 3% to 3 and 1/2 percent of annual revenues in R&D. Those are pretty mature sectors. Average R&D to annual revenues for all of US industry is 2.6%. That includes dry cleaners, right? That's everybody, that's all in. Private energy R&D as a percentage of R&D-- R&D as a percentage of annual revenues is less than 1%. How are we going to do this? And this does not-- this is not good, right? Now, why is it so low in the energy sector? Well, part of the story is that the revenues are so enormous, right? This is a powerful revenue-generating sector. So that's part of it, but it's not a full explanation. This is a sector that's got an economic model and it's sustaining that model, and it's not all that interested in diversification from what's an extremely successful set of approaches.

Now, let's say we up the federal R&D, right? To kind of offset not a terribly pretty picture on the private sector R&D side. When the feds really want to do something big, what kind of money do they spend it on? The Apollo program, over nine years-- now, this is both R&D and implementation. That was $185 billion in 2002 dollars over that nine year period. Carter-Reagan defense buildup, right? That got us know all the stuff we read about in DARPA, precision, stealth, UAVs, submarines that nobody likes to talk about, a bunch of fancy stuff. That was $445 billion over eight years. Doubling NIH was $138 billion over five years. The ballistic missile defense program, which until fairly recently was the largest technology initiative the government had going, its first six years was $145 billion. That's what the government spends when it really wants to get technology done. It's not spending this on energy. OK?

We're not at those levels.

Interestingly, this is energy in R&D spending compared to the price of crude oil. And you can see the remarkable similarities in these lines, right? Price of oil goes up, let's throw some R&D at it. Price of oil goes down, pull that R&D back, right? You can't run an R&D program with sustained results on kind of a roller coaster model. It just doesn't work. This story is not just true for the United States. These are all the developed countries, the OECD countries.

You can see a high watermark about 1980 and similarly coming down to less than half of that. The black line is the one to look at. The International Energy Agency-- which is the energy arm of the OECD countries, a highly respected data collection, energy analytical crew-- in 2008 they did a major study and they concluded that reducing emissions to 50% below 2005 levels. When they added up the R&D as well as the technology implementation that need to be undertaken, they estimated that at a $45 trillion project over a 50 year period, about $1.1 trillion worldwide, $1.1 trillion per year in R&D implementation.

So, you know, that number may be way off. They were guesstimating, we got to do this much solar, we got to do this much wind, we have to do this much advanced nuclear, we have to have this much carbon capture and sequestration. They were kind of adding up what the bill might look like. So it could be significantly off-- but by the way, even if it's off by a whole lot, we're not in range.

So so far, we've been talking about this as though it was a problem we could just shovel money at. Right? That's we've been talking about for the last five minutes. But everybody in this class knows that innovation and a complex legacy sector, like energy, it's much more complicated than just throwing money at the problem. So you've seen these slides before. The US is a covered wagon technology culture, right? We like to leave our old neighborhoods behind and move new technology into open field new frontier kind of innovation, we take our covered wagons west, we go over the mountain, we settle new technology territories. That's what we're pretty good at, we like to do that. We're not good at this problem, right? Bringing technology advanced back into established sectors. We don't do this. And that technology, as we've discussed before, it has to parachute in. And by the way, the incumbents are going to shoot at it on the way down. So it's not just a matter of throwing R&D money at this problem. We've got a much bigger problem, right? Max.

AUDIENCE: Quick question. You said that we're not very good at going in covered wagons east. Is there anyone that is?

WILLIAM BONVILLIAN: You know, developing countries that don't have mature legacy sectors tend to be able to innovate in many, many areas. So that is the story of the stunning growth numbers that China has built over the last 30 years, right? Because there wasn't much there, so they didn't have to overcome these legacy sectors. They were working in innovating in every sector. So they build this remarkable 10% a year growth rate. They've now built out a lot of it. So their growth rate is going to finally come down a bit and it's starting to do so. But that gives you a signal of the kind of growth rate you could have if you were able to innovate across the board, not just in frontier areas. Martha.

AUDIENCE: But is it not just because they didn't have anything there in China, because they're so top-down, they could--

WILLIAM BONVILLIAN: Yeah. I mean, there's organizational issues like that too. But you can look at Korea, you're looking at Taiwan, and you can look at the IT economy in India, right? Another staggering success story of stunning rates of advance. The government had kind of fenced off most of hard industries into a fairly socialist kind of system and pretty inefficient. They haven't fenced off the IT sector and that was not a heavy governmental hand, that was just take off, right? And it's a remarkable story. So it's not always the way-- you don't always need that governmentally hand, but it's an important point.

So the US just doesn't do this very well. The example on the slide is, we don't go back and fix the health care delivery system. We've been fighting over that for about 15 years. We're pretty good at doing biotech, right? That worked. But taking on a whole health care delivery system has proved elusive to say the least.

AUDIENCE: [INAUDIBLE]

WILLIAM BONVILLIAN: Yeah, hospitals and the whole service side of health care. And there's technology tied to that across, too. So a complex established sector is not a level playing field, right? One of the advantages of technology stand up in a frontier is there's no incumbent, you just do it. Right? That's the India story, right? That's the story of the IT revolution in the US. There wasn't anything really quite like computing before computing, it just-- there was nobody in the way. Similarly, biotech didn't really have anybody in the way, whereas these health care delivery or energy problems are much more complicated because you're up against established incumbents.

And these incumbents have strong technology models and systems often with vast infrastructure, right? Think about gas stations and gas pipeline systems. They have an economic model and they've driven down the cost curve, so it's a remarkably efficient system with remarkably low energy prices in the US. There's a massive political support system, right? These are strong regional employers and important parts of local and regional economies, they are very strong politically. And there's a whole social support system.

For many decades, chemical engineering departments were essentially at every unit major university, were essentially part of the fossil fuel system. That's obviously changed, but there was a whole set of academic social support systems that are there. And, look, the US public has an expectation that we get cheap energy prices. Right? Try taking that one on, politically, right? That's one of the political problems with trying to impose a carbon tax. What a wonderful message-- hey, all your energy prices are going to go up, you know? It's not a terribly attractive political message.

And part of the problem here is that the new energy technologies have got to be price competitive the moment they arrive in the marketplace. So we'll get to that problem in a minute. A carbon charge was going to be a way to adjust this. In other words, it would bring the fossil fuel prices up, and therefore, the new technologies didn't have to drive down nearly as much down the cost curve. It would be easy to introduce them. They, in effect, have a significant incentive. We're not going to do that, at least for a significant period of time. So what do we do? Some things we've talked about already, we've got to have a large program that's sizable in scope. In the US, it's going to have to be private-sector led because that's where all the technology and infrastructure is. Government doesn't control it except in certain ways. That means a public-private partnership kind of model is going to be needed. You've got this problem of technology neutrality and avoiding technology lock-in. And, again, we're going to have to think about organizing this one we're getting into now around launch pathways.

So we came up with a kind of a four-step way of looking at launching technologies. So there's lots of literature on R&D and you've read now a fair amount of it by the time we reach class 10 here. But there's very little literature on market launch. It just is not a topic that has been taken up by the science and technology policy literature. So the essentially idea was, think about launch pathways. Different technologies going to launch in different ways. Launching batteries into an automotive sector is a really different project than launching biofuels into the transport sector.

But figure out the launch pathways and figure out for some common launch pathways that certain kinds of technologies have, and we'll get to that in a second. Then, step two is tie those launch pathways to whatever means of policy support you can put to those launch pathways, right? Do a gap analysis in the innovation system, both front end and back end, and then work on filling in the gaps in that innovation system. So a four-step process. We'll take these apart for a minute.

The US has never tried to do anything this tough, right? I think there have been technology challenges themselves that are harder than this, right? Because we can kind of see the strands that we're going to get over the next 25 or 30 years. They're kind of out there. We kind of know what solar is going to be like, we kind of know what wind is going to be like, we can see what's going to happen in storage to some extent. We kind of know what the paths are going to be. And these are not-- this is not like the Manhattan Project, that was a tougher technology project. But this is such a tough implementation task, we have never ever tried to do anything this complex before. So it's a challenge worthy of your careers. It is the big one. Martin?

AUDIENCE: So your focus is policy, Weis's is government because you both wrote a book together, right?

WILLIAM BONVILLIAN: Yeah. Chuck was-- he and I taught at Georgetown and he was chairman of the department, so he was the one who kicked me into teaching some years back. And then, we just got to know each other, decided let's take this book on because we saw that the science and technology policy world, it just not really thought about the details of the technology policy for energy. Obviously, this one, a lot of literature.

AUDIENCE: Because I was thinking it would be interesting if you talked to like a Sloan strategy professor, like a [INAUDIBLE] strategy because they would have some insights into-- because it's not intuitive, usually, like a business component strategy, especially for complex sectors, but it definitely is a way of doing it. Usually you focus on very niche market that you know no one would try to fight you at the beginning and then you grow and you grow.

WILLIAM BONVILLIAN: Right. And we're going to get into exactly that point, too, Martin, that's a very key step in our strategy for a lot of these technologies.

AUDIENCE: And another thing-- another reason too is because it's not simple. Since it's complex, you'll need different business models for different kinds of products, so I feel like they can make a matrix that might be really useful, especially like MIT Energy Initiative, because I'll be like, oh, if you have this kind of strategy, this is a task-- this is how I would go about growing it. And with MIT especially, you have mentors that are going to be there. There are some connections-- it'd be really interesting.

WILLIAM BONVILLIAN: Right. And look-- a lot of this thinking I did was because I got pulled into the MIT Energy Initiative in various ways, and had to think with the faculty teams that are developing these amazing reports that MITI did over the years. I had to understand those reports because I had to help those communities bring their reports to the policy world, so I had to read in pretty deeply-- so a lot of what I'm stumbling onto in the article you read, but also the book that is a larger statement of it really comes out of my MIT experience.

And of course Sloan was pretty deeply involved in each one of those, which was part of what made them powerful. But Martin, when I do the next edition, I'm going to get you to do the business side. So let's go back to step one we'll do a little more detail here so you get what I'm talking about. Let's categorize the launch categories, right? So we know we've got to do a bunch of wedges-- different technologies often embedded in each different wedge. How do we look at launch pathways as a way of looking at the different launch pathways in energy, and seeing if some are similar, then you could aggregate the policy support mechanisms around those.

So some technologies are experimental, and are just going to require long term research. So Max, that's your paper, right? Fusion is still long term, incredible potential if we could get there. We're not really ready for much more beyond R&D and some demonstration commitments at this stage. So that's a federal R&D role-- hydrogen fuel cells, a similar kind of problem. So that's experimental technologies-- that's one category. Just do R&D for those folks. The second category would be potentially disruptive innovations that could be launched in-- you guessed it, Martin-- niche markets, right?

So that's typically how induced innovation works in the private sector. A private sector company will identify market opportunities-- typically a niche market-- take that market, move into it, and start to scale up a new technology advance. That's the LED story-- remarkable success story. They found niche markets that couldn't be dealt with by either of their incandescent or fluorescent technology competitors.

They found niche markets where LEDs were-- a so much better answer than the competitors, and then they scaled into those niche markets, and they used that opportunity to drive the price down so that, when the time came, they could actually compete over that extended time period of driving the cost down to compete with the other sectors. So that's a classic example of launching into a niche market. Solar PV has had some of that opportunity as well-- that's been launched into a bunch of niche markets. But then, there's a more complicated category, and these are-- we'll call them secondary innovations, or component innovations, and this is a lot of what energy is.

Secondary innovations are components in larger systems that face immediate price competition based on price, but they can launch in an uncontested way if the owner of that larger system wants them, right? If that technology is acceptable to that system owner, operator, then they can be accepted. So all they have to do is drive price down, and then they can come in, right? So batteries for plug-in hybrids-- that's a great example here, right?

The auto sector-- they've been burned so many times by fossil fuel prices that's complete wrecked them-- we're on time number three now-- that they're happy to have a much larger share of hybrids, or indeed electrics, in their auto portfolio. So this would not be a contested launch-- they're willing to take this stuff. But you've got to get the price down, which we still haven't been able to achieve yet from really widespread introduction. But that would be an example of a secondary innovation with an uncontested launch.

The hard stuff is secondary innovations with a contested launch. That's carbon capture and sequestration. So the message to a utility company in that situation is-- hi, we want you to do carbon capture and sequestration. This is going to reduce the efficiency of your plant by 40% and add 50% to your costs, or numbers somewhat like those. Is that ballpark numbers, Martha? Is that in range?

MARTHA: And there's no upside-- I mean there's no financial--

WILLIAM BONVILLIAN: Yeah, what's the benefit here? And finance it too-- you finance it, right? And nail your utility customers, right? Good luck. Right? That's what you call a contested launch. The only way these people are going to do this is if you tell them-- they're going to violate criminal laws unless they do it. I mean, that's about all you can do here. You have to regulate these, right? There's no other move. I mean, there are some other categories here, too, that we need conservation and end-use efficiency always needs work, and advances in manufacturing--technologies for scale up.

Those are important as well, but these are the four major territories, the four major launch pathways, we have. And then we've got a whole set of policy packages, all right? So for front end support, right? We do R&D, and-- it would be great to grow some of that R&D. That will help us with experimental, that'll help us in all four categories, because all these technologies need work. Back end incentives, to encourage the technology deployment, right? That's really needed for secondary or component technologies, particularly when they've gotten-- the need for both contested and uncontested.

But you could really use these incentives to encourage, and we've done it, lower prices of automobiles that happen to be hybrids or electrics, right? So we've done those. You can see what I'm talking about here-- tax credits, loan guarantees, price guarantees, government procurement programs, new product buy-down programs-- we've tried a whole series of these. And Congress just renewed a lot of the tax incentives that have been so important to wind and solar for a multi-year period last year, so those are going to remain in place for a while.

But front end, R&D support. Back-end incentives, carrots-- typically for uncontested launch. Niche-- remember, the industry, if it can find a market niche, you don't have to do this stuff. They're going to need help on the front end R&D probably, but if you can launch into a market niche-- that's why it's so attractive to try and find a market niche where we can launch these technologies, right? Because that's a way of starting to scale up, and then buying yourself time to drive down the price curve.

The hard one is sticks, right? So for secondary technologies where you're going to have a contested launch-- the industry sector doesn't want it-- you're going to have to use regulatory requirements and mandates to require this to occur, right? And-- a carbon tax is a form of this. It's organized around-- creating a new kind of financial reality for these kinds of firms. So pick your energy technology, see if you can group it into a launch category, and then step two-- tie your incentive package to those launch pathways.

Follow me so far? OK. Step three-- you're familiar with this by now-- look at the gaps in the innovation system, and you've got to look at the gaps on the front end, and you got to look at the gaps in the back end of the innovation system. And then step four-- duh. Fill the gaps, right? In that innovation pipeline. And that moves from every stage, from research and development, all the way through prototype and demonstration, and testing, and deployment, into a commercial market-- you've got to look at all of those stages, right? And the production phase too, as we've talked about.

We've talked about identifying the gaps in the innovation system-- I'm going to skip this-- some mechanisms that we'll talk about in this class for filling some of those gaps. ARPA-E, arguably-- and we'll talk about this in a bit-- filled a gap in the US energy R&D system for breakthrough technology advances. Maybe we need a better government mechanism for large scale testing and deployment. There's a sore need in carbon capture and sequestration, and we lack a government corporation that can conduct this kind of demonstration level.

That's part of the reason why we just haven't been able to get there in terms of demonstration of that technology. Those are some gap standards-- test beds are part of the gaps. In energy, there is this big problem of new functionality. That's a technology problem you need to understand in energy. IT created new functionality from the outset. So you've heard me tell this story before. I was happy to spend a ridiculous amount of money on my Apple 2E because it did all kinds of stuff for me that I couldn't do before, right?

That would be new functionality. Spreadsheets, all kinds of stuff like that, right? Energy technologies-- first generation, by and large, don't give you new functionality. The nice thing about new functionality is that people are willing to pay a premium if they can do something entirely new. But I don't know whether my laptop is plugged into coal or nuclear power, or hydro, or the sun-- I have no idea, right? There's no product differentiation for me in the way in which I get electricity. Now some utilities-- Connecticut is an interesting example-- are attempting to create that background knowledge for consumers, so they can actually pick technologies they're interested in, but that's not a widespread model yet.

So there's not much new functionality in electricity-- they're all still electrons. It's tough to do product differentiation. Cars, right? There is a difference between a Tesla and-- the thing I drive, right? Because if you happen to be into rapid torque and acceleration, Tesla does provide you similar functionality-- but that's about it. In most driving circumstances, it's just not all that different, and a hybrid certainly is not all that different. Tesla brilliantly figured out, as did Prius, brand differentiation in their market launch.

They figured out how to create a really cool vehicle, and you could sell it on your image of yourself as being cool for buying a Tesla, right? It worked very well in California, and still does does, right? And Prius did something similar, right? You're not just driving a car-- you're bragging about your environmental outlook on the world, right? So this is a way of getting around the fact that there isn't that much product differentiation, there's not that much functionality in the energy sector. I think there will be. I'd like to-- LEDs are quite neat, and you can have a light wall, or a light floor.

And I'd pay for that-- that would be cool, as opposed to a light bulb hanging overhead. That's new functionality, so I'd pay for that. But that's not first generation of energy technologies-- that's not happening yet. It's harder to create product differentiation and new functionality in the first generation of energy technologies, which underscores how complicated the market launch is.

AUDIENCE: There are some technologies that can offer new functionality, if not for the consumer, then for the people are paying for it-- like the utility. One example would be-- fusion produces lots of neutrons, and you could use that to get rid of nuclear waste-- could be nice, and there's virtually nothing else that could do that.

WILLIAM BONVILLIAN: Right. So yes, that may be the silver bullet-- we're just still a while away from it.

AUDIENCE: Nuclear waste is like, a trillion dollar market, so [INAUDIBLE].

WILLIAM BONVILLIAN: Right. And the problem for the utility companies is, to adopt new technologies they-- generally speaking-- have to pay more, right? Although we're working on driving those costs down.

[INTERPOSING VOICES]

WILLIAM BONVILLIAN: We made a lot of progress.

AUDIENCE: What I'd look into [INAUDIBLE] like a process, it's a whole supply chain for energy, so lines, where you produce it, when it gets over, and what dissipates. So figuring out how the supply chain is flawed to create products that fix the supply chain, so it's a lot better, and they don't have those [INAUDIBLE] by the way. That's the product, right? This system is broken, I fix the system with this product, and so because energy is going to come out either way the same way, right? That's how I think about it.

WILLIAM BONVILLIAN: Right, and you can think about smart grid options that do create new functionalities as well

AUDIENCE: Or mobile energy sources that can be near cities, because then you don't have to transport them long ways. And-- especially for disrupting big companies, they spend so much money on putting the lines, and they have to pay for regulations, and it slows them down. So a new mover can do something like that, and disrupt them.

WILLIAM BONVILLIAN: Right. Finding those market niches is a task that is now upon us, because we're not going to do a carbon tax. So let me just recap for a minute. You have to apply all the innovation models-- pipeline, induced, extended, manufacturing led, innovation, organization. You've got to think about this, and [INAUDIBLE] by looking at all the dynamics of innovation and how to organize them.

And we need the four step process here-- figure out the launch categories, group them with similar technologies, apply the right incentive package to that category. Look at the gaps in the innovation system, and work on filling those gaps. So that's the four-step process we've got so far. That's enough. Why don't we do some Q&A here? Sorry for that extended wrap, but you basically now know everything I know. Who's got this one?

MATT: I have.

WILLIAM BONVILLIAN: All right, Matt, all yours.

MATT: Yeah. I think you managed to be more thorough than the reading example.

WILLIAM BONVILLIAN: That's because there was a book behind it, but I didn't want to make you buy two of my books-- one is enough.

MATT: I guess my main innovation was very similar to Max's. I think all of the other readings for this week-- look at things that the US is trying, but I think it would be really interesting to talk about learning opportunities. You mentioned China, and it still seems like that's-- maybe to me at least-- not going back east as much as going into--

AUDIENCE: The centralization?

MATT: Yeah.

AUDIENCE: [INAUDIBLE].

MATT: Sure, yeah. And just not making the same mistakes that we made, setting up first.

WILLIAM BONVILLIAN: Well, they are standing up two thousand-megawatt coal-fired power plants a week still.

MATT: So are there true examples of really innovating, where you already have a legacy sector.

WILLIAM BONVILLIAN: You know, when we read that reading on DARPA a couple of classes ago, as we talked about at the time, the defense sector-- it's a legacy sector, right? It's very locked into its technologies, into its social organization, into its economic and budgeting models. It's very hard to innovate there-- you're up against a lot of established systems there. Yet DOD has been able to bring on a whole set of very interesting advanced technologies over the last 25 or 30 years.

So it does tell you that this is not Mission Impossible, and there are organizational lessons-- as you've read in the textbook-- that we can pull out of DOD. Part of it has to do with some of the rules that we've talked about previously. Part of it has to do with finding a community of change agents, and that's very, very critical. So you need to develop the new technologies. You use an island bridge model to attempt to get the decision maker community to force your approach on the overall system.

And then to do that is going to require a community of change agents. And there are communities of change agents that we're starting to see in energy. I do think that we are entering into a very significant energy innovation wave, and we can already start to see some of the outlines. We've seen a fracking revolution in the United States that has completely changed the landscape of US energy dependency, and it's very dramatic. I mean, the entire energy supply system of the United States has been turned upside down-- something which nobody ever thought was conceivable, right?

And that is a set of technology advances that were originally pushed by several of the energy laboratories, developed that core technologies behind fracking, and proceeded to-- it was implemented over about a 15-year period as something by a wildcat maverick community in the natural gas sector that took these technologies up and worked on implementing them, and it really changed things. And the United States leads that technology revolution, so we have 100,000-- now there's a lot of debate about a lot of these operations, the environmental consequences of them.

We have about 100,000, roughly, net fracking operations ongoing now in the United States.

The country closest to us is China-- it has about 6,000, all right? So we have a big lead on that energy technology revolution. We have-- we can see-- solar and wind now, which are now scaling up to trillion-dollar worldwide energy sectors. They're going to be very, very big, right? So this revolution is now starting, right? The real question for the US-- and we'll talk about this more later-- is whether it's going to play, right? Whether it's going to ride this wave.

MATT: Yeah, it definitely seems like a theme of the class. DARPA worked-- let's try ARPA-E for energy, or a DARPA-like funding model for NIH.

WILLIAM BONVILLIAN: But it's a more complicated process than just having a DARPA. DARPA can be a change agent, but you've got to get these steps down too, right?

MATT: Right.

WILLIAM BONVILLIAN: When you work on the implementation side.

AUDIENCE: Actually, regarding the ARPA-E. I notice that DARPA has a budget of funds like $5 billion?

WILLIAM BONVILLIAN: Three.

AUDIENCE: OK, $3 billion-- whereas ARPA-E has a budget of-- maybe $100 million? Couple hundred million?

WILLIAM BONVILLIAN: $300 million. 306, Martin, right?

AUDIENCE: How is it we can expect that ARPA-E is going to do what DARPA did if it has a tenth the budget?

WILLIAM BONVILLIAN: So I want to save exactly that question for our ARPA-E piece. Is that OK? Would you forgive me, but bring it back?

AUDIENCE: That's fine.

WILLIAM BONVILLIAN: All right. How about it? What else we got, Matt?

MATT: I don't know if you want to go here, but you did mention and allude to this earlier, that--

beyond energy like this is a framework that can be used for any legacy sector. I think a lot of our papers are applying the framework. It's interesting to see if there were any insights into how it becomes specific to whatever industry wants [INAUDIBLE]. I don't know if you wanted to move away from energy.

WILLIAM BONVILLIAN: It's a very good question, and the purpose of our textbook was really to take lessons that we've thought about in energy with the realization-- oh, we knew energy was a legacy sector, and we realized-- oh, wait a minute. Most of the economy is a legacy sector. Oh, we came up with this four step process energy. Maybe we could think about that four step process for a lot of other stuff, too. That was frankly-- a little more sophisticated than that, but that was the essence of our conceptual realization process.

So-- I do think that these steps here are steps that you've got to think through when you're innovating in a legacy sector. You've got to think about the different innovation models you've got, and how to organize those in new ways, because all of them are going to be required in the legacy sector-- but you also have to think about, what are your launch categories? What are the barriers to launch?

How are you going to overcome those barriers? What's the right incentive package and support system? Can you do niche launch, which gets you out of this whole box? What are the gaps in your information system? I think you've got to go through all of those when you think about legacy sector innovation in general, and we did a little of that in the health care discussion last week.

AUDIENCE: When I was looking at this, I was thinking a lot about edge cases in computer science-- like, what if I got the best product, right? And then tried to go through the framework, and see how I would pan it out. So say like fusion, right? How would it work out, and how is the system structured to help bring innovation? So-- in ideal innovation, how would it work, and how would the dynamics be? And then also, a horrible innovation, right? It's really not even innovation. I think Tesla got caught on this, that they were doing the same battery technology that ARPA-E [INAUDIBLE] figured out, and they're trying to get government incentives and go through.

And so-- that way, you can figure out-- this is really not innovating, but they're trying to use these resources. So I think that was a really interesting thing to maybe try to do in the future-- different types of-- because there's all the categories of energy technologies. What if you try to figure out the ideal solution, and try to push it through the framework? How would they be able to function? Because that way, you can also find organizational gaps, like the politics would not allow it, or other things. I thought it was interesting.