PROFESSOR: Bob has got a really interesting history I think is relevant to a lot of things we're talking about. You're going to hear a little bit about disruptive innovation, you're going to hear about someone that's spent a lot of time on renewable energy, trying to get new technology to the marketplace, and about kind of the trials and tribulations. So I would encourage you to kind of really ask lots of questions and enjoy yourself. Bob, thanks very much.

BOB DIMATTEO: And you can ask those questions right from the beginning, so I would encourage you to just raise your hand anywhere along the way. So when I was your age, I sort of wondered about why there were little kids in the world that didn't have clean water to drink. And that sort of bothered me.

And it was that kind of thing really got me interested in engineering and got me interested in clean energy. And it's hard to imagine like 30 years have gone by since that happened. I mean, you guys aren't even 30 years old. That seems like forever.

So I'll tell you about MTPV. This is a clean energy technology that our startup company is developing to bring to market. And I'll also tell you something about my own personal journey in clean energy. And happy to take it wherever you want to go.

So maybe I'll do a couple of slides on sort of the technology, and then you'll know where I am at the moment, and then how we got here, and then we could go from there. So our technology is called MTPV. It stands for Micron-gap Thermal PhotoVoltaics-- blah, blah, blah.

It draws on nanotechnology, MEMS, and photonics. And what really motivates us is that we think that it has the potential to change how we think about energy because it's a way of applying these very powerful techniques-- the whole chip that we see in our iPhones and we see changing so many aspects of our socio-technical life, if you will-- bringing these kinds of capabilities to bear on the energy world.

Which in some ways is, as you've been learning in this course, is in some ways, it's changed a lot, and in some ways, it hasn't changed very much in the last 100 years. We still make heat from things that we get from the ground. And then we do things with that heat, consume it as heat or turn it into electricity, et cetera.

Our technology turns heat into electricity. And so we start with photovoltaic cells. You're all familiar with them. You see them on buildings these days. It wasn't that many years ago when folks really didn't even know what photovoltaic panels were because you didn't see them around. It's quite remarkable.

In fact, when I was just about getting ready to finish undergraduate work was just about the time that President Reagan took the solar panels off the White House. Now they weren't solar electric panels. They were just they were just hot water panels.

But clean energy wasn't-- it wasn't the primary focus of too many folks at that point in time. MIT actually in that time frame had a solar house, even. Sort of modern architecture, lots of glass solar house that later came down about 15 years later. But now lots of things are moving in that domain.

So we start with a photovoltaic cell. You're familiar with the sun putting photons on the semiconductor material and making electricity. There's another field called thermophotovoltaics, or TPV, where we have an intermediate body which receives the heat-- the heat can come from any conventional sources or solar.

And this body at-- right now, what we're doing is around 1,000 degrees Celsius, things start to glow red around 600 degrees Celsius. So this is very hot. It radiates photons. It glows red. And those photons-- and then converts electricity by photovoltaic cells. So how many of you have heard of Planck's law?

OK. So Planck's law was sort of the foundation of quantum mechanics in modern science in the 20th century. And Planck's law tells you how many photons come off a heated surface and what wavelength they are. And so the photon flux, the number of photons coming off that surface per square centimeter is given by Planck's law. And we represent that here-- 1x Planck's law.

And there were reasons that we thought that if you brought that real close, you could do near-field coupling and you could exceed Planck's law. And it was somewhat controversial in the beginning. In fact, in a meeting with Hermann Haus, who was a real power house in electrical engineering and photonics-- unfortunately, passed away a few years ago-- the first time we came in his office with this, he said, forget it. He said, there's just no way to violate Planck's law.

And about an hour later, he realized that we weren't really violating it, that we were operating outside of the limits of applicability that Planck himself had put on the law. Planck's law says that the geometry of all the pieces of the system have to be large compared to the wavelength.

And one of the geometric pieces of the system is the space between these two surfaces. So literally, the gap between the hot surface and the photovoltaic surface. In MTPV, Micron-gap Thermal PhotoVoltaics, we put them really close together, like 100 nanometers apart, or 1/10 of a micron. And when you do that, you get near-field coupling and the photon flux, and therefore, the power out can dramatically go up by about an order of magnitude.

And so he said, oh OK. He said, so you actually want to put the photovoltaic cell into the near-field or evanescent field of this heated surface. And we said, yes, exactly. He said, OK. Well, maybe you can do better than Planck's law.

And so really this is the field that we've been pioneering, using this mechanism which basically derives from the fact that inside the hot body, there are photons generated in every direction. It's only the photons generated inside that come up to that surface-- normal to the surface or nearly normal to the surface-- that actually get out.

So in a hot body, most of the photonic energy that's being generated all the time is trapped inside. But if you bring a surface up close enough to it, as those photons approach the surface, a photon is-- as Professor Haus pointed out-- actually has extent, it has size of something on the order of the wavelength.

So we don't usually think of photons as having a size. But they have an approximate size, something like the wavelength. The wavelength we're working with is 2 microns. The gap here is only 0.1 micron, so this big 2-micron photon comes traveling up towards that surface, and just goes right across this vacuum gap between the two surfaces, act as a photovoltaic cell, and then can become power.

So it's all the photons that are impinging upon the surface off-normal that get into the photovoltaic cell here, in our technology, MTPV, that do not get out of that hot body. They're trapped inside the hot body there. And that's what causes this increase in power.

So why do we bother doing that? We think that there are a number of places of application-- I think, in the course, you guys have contemplated-- or about to contemplate a number of different sources of energy as well as uses of energy-- so one of the application domains is vehicles. And we'll come back to this slide at the end to discuss it in a little more detail. There's solar energy, portable power, industrial, which is the first one that we're working on right now.

The other one not shown is building power, a cogen for a building like this. So the first one is waste heat. There is lots of waste heat in lots of places. The focus right now for our technology is industrial waste heat, the kinds of things that you see in these pictures, specifically a glass plant.

These are the basic modules. These are the chips of which you saw a schematic a moment ago. So this is actually a chip stack. Each one of these is a pair of chips-- the hot chip and then below it, the cold photovoltaic chip. So we build them into arrays. And then we take these modules and we build those into arrays, like this, where we have a housing on the outside and then the chips go on a mounting and control substructure, if you will, which is mounted inside of this hollow housing.

So the hollow housing protects from the outside combustion gases, et cetera, allows the heat to go through the surface into the chips, makes electricity. And that's it. It's a very modular technology. And that's one of the promises of it, that it can be deployed-- we call it kind of noninvasive.

And you've talked about disruptive technology some in the class, which has become an important understanding in the business of bringing all technology-- and not even just technology, but products to market. And the idea of disruptive technology is the new technology comes along and it's not very good, technically, compared to sort of the incumbents that are on the market.

But it finds a niche where it can perform. Often the niche is called noncompetition. So developing a product-- you look for a place where there is no competition. And this is an example of a place where there is no computation.

This sits outside a coal mine. Coal mines nowadays, they go down in the ground, and then the coal-- and then the front, the digging front, if you will, the interface between the air and the mine and the coal that's still on the ground, it comes down and then proceeds horizontally. And one of the issues with coal mines, as-- is there anybody who has not heard of a-- let's see how do we want to ask it? Has anyone heard of a coal mine explosion? Raise your hand.

OK. So most folks have heard of coal mine explosion. So why the coal mines explode? Any guesses?

AUDIENCE: Methane.

BOB DIMATTEO: Please?

AUDIENCE: Trapped methane.

BOB DIMATTEO: Yeah. Trapped methane, exactly. Whenever you're digging up coal, you also liberate trapped methane-- natural gas-- very explosive. And so they go through lots of ways of controlling the methane content in the air so that the coal mine doesn't blow up. But they do blow up some time.

And so what people have started to do is drill down in front of the coal mine-- there's this vertical face that's coming horizontally under the ground-- they drill down into it like this and they liberate the methane in front of that. And then what do they do with the methane?

Well, this is what they do with methane, believe it or not-- oftentimes. I mean, if it's big enough, if it's stable enough, then they will actually feed it into a combined cycle or some type of combustion system to make electricity. But first of all, the coal mine front is moving and steam turbines don't like to be moved. And so that's why you see this very portable looking infrastructure here, that they actually move it as the coal mine is moving.

And what they need to do is they just need to destroy the methane. So here is methane being destroyed in that inner pipe there. And the idea is to just take panels like this, and to run them down the middle of that tube and to turn that into electricity. And so no one's really doing this right now because of some of the reasons cited. You could do it with-- maybe we should ask the question.

So are some of you are familiar with steam turbines, or? OK. All right. So you could imagine putting condensers in here, gathering steam, and running steam turbines, and making electricity. But the idea is if you had a module-- sort of like a photovoltaic module, but made out high-temperature materials that you could put in it, easily move, that would be preferable.

And the reason that this is sitting here in this picture the way it is because the steam turbines are not feasible now. And so what we're going-- this is an example of noncompetition in the energy space-- and clean energy space in particular, because it would be a way of making electricity with zero net emissions relative to the status quo.

I mean, this is the status quo. So those emissions are going out anyways. If some of the heat can make electricity, that electricity's zero net emissions. So this is an example of noncompetition. We go after that, we could not compete against GE's gas turbines right now. The performance of our units are not good enough to do that. But they are good enough to do this in the near term.

And just as the original integrated circuit chips, when they first came out, they didn't immediately displace tubes. But they got better and they got better. And I think Hiram talked about the disruptive example of the Sony radio. There were still tubes in radios for some amount of time after those chips were in those tiny little radios.

And so you could kind of view our chips as an analog to those chips and those transistors. And this is an application to the transistor radio. They had the transistor radio had to be able to move into kids' bedroom, et cetera. Here, it has to be able to move with the front of a coal mine.

Another application similar is combusting volatile organics as they're loaded on and off of ships. So in the back here is a harbor-- this is down in Houston. In the very back, you can actually see a little tiny flare, which basically a flame sticking out of pipe, which is the older way of doing these things in which people have tried to eliminate because flaring of-- flaring of natural gas reduces the greenhouse impact by about a factor of 20.

So if you have natural gas and you just vent it to the atmosphere, and you compare that with burning the natural gas before you vent it, you reduce this global warming impact by a factor of 20 by burning it. So in a way, flares are a big advance on just venting natural gas. But flares have their own pollution issues.

And so what has become prevalent, particularly in the most developed countries at least, are enclosed flares. So this is a stack, basically. And it encloses a flare like this flame. So as the ships are loaded here, the volatile gases that fill the tanks before the liquid goes in gets pushed out and it has to go somewhere so it doesn't explode.

And where to go? It goes to this right here. It gets burned, and that heat is just liberated. And so we are working with a vendor that would put our panels right across this tube, right in this flame to convert that heat into electricity.

So it's another example of nonconsumption. I mean, these things are running all the time. And that heat is not being used because there's no good way to do it right now.

And this is just another example of the same module that you saw. Bigger panels-- this is the kind of panel that might go into a glass factory, which is depicted here. So natural gas comes in here, it burns, it melts sand, and lime, and things, which get pushed into this big furnace with bulldozers-- literally, it's quite amazing.

And they melt it and it becomes like volcano lava, sort of, in here-- it's actually glass. And then out the other end, it slows down and becomes plate glass like for the windows up there, et cetera.

And so this is the exhaust duct. The exhaust comes up here, and right now, a type of furnace called oxyfuel furnaces where oxygen is taken out of the air and put it to the furnace, they create the heat. The heat just goes up the stacks. Our panels would go in there and convert that to electricity. That's actually the first application that we have-- that we are working on developing.

So I'm thinking about pausing at some point. And I guess one question is, how many of you are not electrical engineers? OK.

AUDIENCE: Lots of chemicals and mechanics.

BOB DIMATTEO: OK. How many of you are not chemical engineers? OK. And how many of you are not mechanical engineers? How many of you are bio-folks? OK. All right.

OK. And I know we have some DUSP, and some poli-sci folks, and ocean engineer folks today. So OK.

So this right here is an actual picture of the same kind of furnace that you saw-- actually, the exhaust port of it. And this is the same kind of housing that you saw. And this is some initial testing that we were doing moving the panels in and out of this facility. This is an earlier version before we came to this-- what we call product platform, which is the basic architecture that we've been talking about to date.

RICHARD SCHMALENSEE: Do you want to say a little bit about the journey that got you from an undergraduate interested in energy to this?

BOB DIMATTEO: Sure. Yeah. I'd be happy to do that. Yep. I initially kind of got interested in this kind of market here. And how many of you think you might someday start a company or be part of starting a company? Wow, that's a lot. That's more than-- well more than half the class. OK.

AUDIENCE: [INAUDIBLE] energy.

BOB DIMATTEO: So what are some of the ideas you're thinking about, just to get a few examples on the table? Samuel?

AUDIENCE: Well, I think solar thermal fuels could be cool.

BOB DIMATTEO: Solar thermal fuels.

AUDIENCE: Yeah.

BOB DIMATTEO: So building like liquid or gaseous fuels out of solar thermal energy?

AUDIENCE: Yeah, like finding some molecule which can like-- acts as like a photoconverter and take the sun's energy and store it as chemical bonds.

BOB DIMATTEO: OK. OK. Sort of artificial photosynthesis?

AUDIENCE: Yeah.

BOB DIMATTEO: OK. All right. Cool. Somebody else? A lot of hands went up for starting companies, including energy companies. Oh come on. Yes. Back there.

AUDIENCE: Biotechnology.

BOB DIMATTEO: Biotechnologies. OK. Can you say, in the energy context or different than that?

AUDIENCE: Probably not energy context.

BOB DIMATTEO: In the energy--

AUDIENCE: No, probably not.

BOB DIMATTEO: Probably not. OK. What realm? Medicine, or?

AUDIENCE: Yeah. Probably something to do with medicine and pharmaceuticals.

BOB DIMATTEO: OK. OK. OK. Someone else-- either energy or not energy. Let's see, who else had their hands up? Engineers are so engaging.

[LAUGHTER]

I love them. I spend my whole life with them.

AUDIENCE: A lot of folks defeat the stereotype.

BOB DIMATTEO: So what else? Even if you're not interested in it yourself, something you know that somebody else might start? Christopher, yes?

AUDIENCE: Yeah. A system for converting hydrogen into ammonia for fertilizer.

BOB DIMATTEO: Oh interesting.

AUDIENCE: Because like I'm originally from Iowa, and most of the things we have a lot of is water and wind. And wind energy electrolysis to produce hydrogen, and using that to produce ammonia because we also have a lot of farms in the area.

BOB DIMATTEO: So then that fertilizer would go into the food production then.

AUDIENCE: Yeah. Because wind energy, a lot of times where the windmills are is far away from where the electricity is consumed and you lose a lot to resistance. And so would be economically more efficient to produce ammonia out of it.

BOB DIMATTEO: That is a really cool solution to having to ship-- build big grids and ship the power all around. So there's wind in Iowa, and there are farms in Iowa-- wow, that's neat. Somebody else?

All right. Let's see. So who has not-- who is thinking-- who is not thinking about starting a business? All right. So do you mind if I just call on a couple of you to say what you're thinking about? Latifa?

AUDIENCE: I have no idea.

BOB DIMATTEO: But you think you might start a business.

AUDIENCE: I mean, maybe, if the right idea comes along. I mean, [INAUDIBLE].

BOB DIMATTEO: OK. OK. Yeah, Scott?

AUDIENCE: I think for myself, and I'm guessing for a lot of people in the room, I want to start a business at some point, but I don't have any good ideas yet, which is why I haven't pursued that yet. So I think that like a lot of people at MIT have the entrepreneurial spirit, but just don't have the good plans yet.

BOB DIMATTEO: OK. That's important. Yes. First name?

AUDIENCE: Sean.

BOB DIMATTEO: Sean?

AUDIENCE: Yeah. Well, for me, I think even if I were to have a good idea, I don't think I would even venture into trying to start a company at this point in my life. I think that there is valuable insights I could gain by working in industry for a while, whether it's engineering or not. And as you get more experience, you actually understood how things work in reality. Then at that point, the idea that you thought it was good, maybe it wasn't. And if turns out to be, then you'll have more experience to actually make it happen.

BOB DIMATTEO: Makes a lot of sense.

AUDIENCE: It's not about the idea. It's about the experience.

BOB DIMATTEO: Absolutely. Right. It's the idea and everything else it takes to turn that into a product, doing something useful for people in the real world. OK. One more input, just to have a little collection of inputs. One more-- anyone want to jump in. Columbus? You thinking about what-- what year are you in?

AUDIENCE: I'm a senior.

BOB DIMATTEO: Senior.

AUDIENCE: It's the intersection of kind of the environment and energy sector. So how renewable impacts on environment [INAUDIBLE] energy system. So I'm not really sure.

BOB DIMATTEO: OK. OK. Good. So just based on the very little you know about our technology, make an argument for starting-- which one you would start in. Because one of the most difficult things in launching a business, whether you're doing it as a startup or whether you're doing it in an existing large company, is what market to go after first, right?

And there are advantages and disadvantages to different markets. One of the advantages doing something in a large company is you may be able to go after more than one market at the same time. But oftentimes, not.

So it's sort of like selecting a spouse, right? There are lots of different interesting candidates in the world, right? And how do you narrow it down to one particular person? It can be a painful process?

And so this can be a painful process, too. So somebody say something about why you would or wouldn't choose one of these four as an initial launch market? Yes, Samuel?

AUDIENCE: I would say take the one with the lowest barrier to entry.

BOB DIMATTEO: Lowest barrier to entry. So what do you mean by barrier to entry?

AUDIENCE: Like thinking about like what sort of things are going to stand in the way from getting your product into actual use. And I mean like things where there's a lot of infrastructure to go through, or even like really established industries, they can be kind of hesitant to take on new technologies, where things that are kind of less established oftentimes will be more open to just changes.

BOB DIMATTEO: So how might you address that-- did you have, right here?

AUDIENCE: All right. I did have something to say--

BOB DIMATTEO: Yeah, please, go ahead.

AUDIENCE: [INAUDIBLE]. Oh, I was going to say, if I were to choose, I'd go in more of a [INAUDIBLE] because it seems like the market is there. And it seems like it's growing, like not only [INAUDIBLE]. And I think that there'd be more potentially. Like, [INAUDIBLE]. But since solar's more, I guess, uncertain, it's more uncertain than like industrial, like it seems like there's a lot of [INAUDIBLE] happening in there right now. Automotive-- I guess that would be my second choice if I had to choose right now. [INAUDIBLE].

BOB DIMATTEO: OK. These are really good inputs. Charlotte?

AUDIENCE: I think I would go with industrial, just because a lot of-- I mean, for solar power in like industrial areas. A lot of times industrial plants are located like outside of cities, where there wouldn't be as much like interference. And I think that-- I mean, obviously, like industrial plants produce-- like use a lot of energy [INAUDIBLE] generation, so that seems like a market.

BOB DIMATTEO: OK. Very interesting. So we have low barriers to entry, portable power, industrial sector, right? Interesting. John-Mario.

AUDIENCE: Yeah. So I think-- I mean, all of those four are pretty capital intensive as far as starting something goes. So I think scalability will be a big factor. So that's one thing also industrial is very interesting, because if you look into a lot of, I guess, clean energy initiatives tend to be very focused on like the utility sector, how you can make things more efficient-- or industry, in terms of manufacturing.

And I think personally, there's too much emphasis focused entirely on just-- for startups, just in technology per se. But I don't personally see that meaning, for example, consulting firms advising how startups can secure government grants, or how startups can position themselves to take advantage of existing policies related to energy or something like that.

I think there are a lot of different areas that you can use knowledge about energy and so on, but without necessarily producing anything, mostly advising for this as well.

BOB DIMATTEO: So there's a lot more than just the technology.

AUDIENCE: Right.

BOB DIMATTEO: OK. These are all really important points. And as engineers, that may be one of the hardest ones to get. It sounds like you guys probably already have a very good sense of that, the ecosystem, that there's more than just the technology. But oftentimes, the technology is hard, so it takes lots of your focus. But then you've got to make all these other decisions.

So in our case, we really struggled with portable power because it's small. And so compared to the industrial, industrial, you need like more chips, which requires more capital, more manufacturing capacity. You've got to deal with bigger vendors, and there's more bureaucracy and everything else.

And so the portable power was very attractive to us. We ended up going with industrial, OK? And so any guesses as to why we might have done that? Yes?

AUDIENCE: From what I've seen, your technology is most aligned with them. They have very energy-intensive processes that are also capital intensive. And a 4% or 5% efficiency gain, something that's valuable to them in the long term. And they also have a long lifecycle. It's not like a laptop that has a two-year lifecycle maybe, you're not going to get a return. So it's not 1,000 degrees.

And you have a much more diverse [INAUDIBLE] whereas here you have maybe 20 major players. They all have enormous plants that operate at high temperatures. I think you make the decision to save 5% with your capital.

BOB DIMATTEO: Yep. So that was definitely part of it. Performance-- how good a performance? You start with the technology is just new. How good does the performance of the technology have to get before you can do X market?

And here, we felt that it was more stringent because here-- say, we're going to go into a laptop. We had to compete with the lithium ion batteries that are in laptops. And so this kind of goes to technical details, really. But that was a factor, that we felt-- there's no way you guys could know a priori sitting here.

But we felt that it would have been harder to get that level of performance, as opposed to the industrial situation, where it just-- basically, it's economic. It needs to be economically feasible. But it doesn't have to be any better than that. And there's really no competition.

Another thing was-- some of you guys mentioned related things. And that is, how tightly do you have to integrate with other companies, with other technologies, with other applications? And we felt that in the industrial-- for example, the heat source. What kind of heat source are we going to use? Where are we going to actually get the heat?

Here, the heat would have to be produced in a very small combustion device-- a pretty high-tech combustion device. And so we would need to very tightly couple with another company to do that, as well that the heat rejection, safety, FAA regulations, et cetera. Whereas in the industrial space, the heat was already there. So it was just another piece of complexity that we didn't have to deal with.

OK. So let's see. Let me-- that's about all I have for slides--

RICHARD SCHMALENSEE: How about your life story?

BOB DIMATTEO: My life--

RICHARD SCHMALENSEE: How did you get from undergraduate kind of interested in this stuff to selling to glassmakers?

BOB DIMATTEO: Yeah. So my life story-- so you really want everybody to be able to take a nap right now--

RICHARD SCHMALENSEE: Doesn't have to cover all aspects of your life.

BOB DIMATTEO: No, I know. I'm just kidding. Yeah. So I mentioned at the beginning what kind of triggered it, right?

And I guess there were two things-- then there was an energy shock in like the '70s, when I was a kid. And then I was in late '70s in college. And it looked like energy was really important. So I guess you guys are sort of-- the fact that you're in this class-- the fact that this class exists and the fact that you guys are in this class means that energy has gotten a lot more visibility now than it did, say, in the '80s.

So at any rate, I started-- what got me actually started was an article in *The Boston Globe* in 1978, in the summer. I was sitting down the Cape, at my girlfriend, later wife-to-be's cottage, reading *The Boston Sunday Globe* on a Sunday. And there was an article that said, "Kid in Texas Gets 100 Miles per Gallon From '68 Ford Galaxie."

'68 Ford Galaxie was a big car that probably got like-- I don't know-- 8 miles per gallon on a good day-- right-- 100 miles per gallon. So could that be true? So who thinks that it could be true? Who thinks that it could not be true? And who's not sure? Good. OK.

I'm not sure. No, I mean, it all depends on how you define the vehicle, et cetera, et cetera. There are only so many BTUs in a gallon of gas. At any rate-- so it led me to the-- I was thinking about medical school. I used to-- I studied at a school down the street at the other end of Mass Ave. So I used to drive by this place.

I have three graduate degrees from this place now. But the way I really discovered it was driving down Mass Ave. i mean, obviously, I knew about MIT. But I really didn't-- I really didn't understand what engineering was.

I thought if you liked math, and science, and stuff like that, well, you could be a doctor, you know? So I figured, well, maybe that's what I'll do. So I was a government major because I was interested in the kinds of things that you talk about in this course. But I really like math and physics-- science and math. And so I figured, well, I'll do medicine.

And then I read this article, you know? And so then they kind of came together, just like you guys are doing in this class. You have technical backgrounds of various sorts, and you're here learning about the whole picture of energy, which really is-- I mean, in some ways, unfortunately much bigger than just the technology because it makes it much more complicated. But in a way, that's what makes it that much more important.

And so did early experiments in this realm, found out about solar energy and photovoltaics. Came over here, and Steve Senturia taught the class on microfabrication, the interest in photovoltaics brought me there. I ended up spending a semester here while I was an undergraduate down the street, which, if any of you are not seniors, I highly recommend just get yourself down Mass Ave, take just one course at that other institution.

It's totally free. It's totally easy. It's a very different world and you'll be glad that you did it. You can write me for your money back if you don't think so afterwards.

At any rate, so I started my first company while I was a senior in college specifically to develop energy technology. And it took probably 15 years to really do it directly, which is this right here. Although, along the way-- so from in the family garage, tinkering with engines and trying to figure out, can somebody really get 100 miles per gallon, and patient family kind of dealing with all that.

And then right then in the beginning of the '80s, difficult recession, where do you get a job? Do you really want to do clean energy? There are no clean energy jobs. And I went to work in the aircraft industry because I also taken Fred McGarry's course here in composite materials because I was interested in composite materials for what? Why might you be interested in composite materials if you're interested in energy?

Wait a minute. We got to get somebody else, John-Mario. Thank you. Come on. Kristin?

AUDIENCE: Lightweight vehicles?

BOB DIMATTEO: Yeah, exactly. Exactly. Right. Exactly. Yeah. And so they wanted to build lightweight helicopters. And so later on, I realized that I-- wasn't so clear at the time that I was really working on clean energy-- you know, lightweight, strong materials which are now going in lots of airplanes and vehicles.

And I thought I was in the aircraft industry, but I was really working-- pursuing my interest in clean energy. And then another stint with a company up the street, MITRE Corporation, another spin-out out of MIT-- well, Lincoln Lab spun out of MIT, and MITRE spun out of Lincoln Lab.

And when we started to explore some of these concepts-- but I really wanted to try to do things more directly and linked with sort of energy as the food piece that Christopher mentioned. And sort of the notion that if a home-- if a home-- it's part of like-- like what's an energy system in a home? I know this is real easy, but what's an energy system in a home? That every home in the United States has? Yeah, Jacob?

AUDIENCE: HVAC.

BOB DIMATTEO: HVAC. Exactly. So make making heat, keep people warm in the cold weather. And what's another energy system in the home?

AUDIENCE: An oven.

BOB DIMATTEO: Oven. OK. And what might the oven run off of?

AUDIENCE: Natural gas or electricity.

BOB DIMATTEO: Or electricity. OK. So then electricity is another energy system. So one thought is, what if there was a food system in a home also-- going back to Christopher's point. And so just the notion of the home as being the energy central of your physical well-being-- whether it's in the developed world or developing countries, even more important perhaps, in developing countries.

Any rate-- so it made me want to build a house. And I built a house while I was working full-time and then built another one. And so then I did that for about eight years. And we were leaders in energy efficient housing-- no surprise.

And over the course of time, we built some miles of roads and 150 homes. And then I went back to graduate school to more specifically concentrate directly on energy technology and the kinds of issues that I talked about earlier. And that's what led to MTPV with the professors here.

And then there's a laboratory across the street, Draper Laboratory-- it used to be the MIT Instrumentation Lab. And they called me up and said, we saw your resume in the course 6 resume book. And now this was and-- this is in 1996.

And energy-- so how important-- how hot a topic was energy in 1996? Not for those of us that were working in the field and dedicated, but I mean, do you guys have any sense? How old were you guys in 1996? Just a couple of examples, ballpark?

AUDIENCE: Six.

AUDIENCE: Four.

AUDIENCE: Five.

BOB DIMATTEO: Six, seven, OK. So it wasn't on the top of you guys' agenda, right? But do you have a sense of like how relevant it is today? How much in the news it is today versus in 1996? More now or less now? How many think it's more now than then? OK. Yeah. So it certainly seems that way.

But at any rate, there were folks over there that thought energy would be important. And so we started developing this MTPV technology there. First analysis, the visit the Professor Haus mentioned earlier here on campus, who once he realized that you actually could do better than Planck's law, that we weren't violating Planck's law, that we were just operating outside of the limits that Planck himself put on his law, he said, OK, go run the numbers.

So go back and crank through Maxwell's equations and do all that stuff. And come back and tell me how much more-- how much better can you do that Planck's law? And so with a tremendous team at Draper Laboratory, many of whom we still work with today, we did that.

And then-- so this is part of-- one of you guys here mentioned starting in a larger company, right? What's it look like starting an energy technology in a startup versus the larger company? In the larger company, there is management to deal with. Management does the resource allocation. And hopefully, which was the case for us, they ask good questions.

First they said, go convince Professor Haus that you have it all right. So when the analysis was done, then they said, OK. Now you're ready to design experiments, start doing the experiments. We built tiny chips, 2 millimeters by 2 millimeters-- so smaller than half your baby fingernail.

And sure enough, the effect was there as the theory-- as the analysis predicted. We published that in *Applied Physics Letters.* The government got interested-- somebody mentioned government funding or whatnot. That can be a very important part of energy technology because how is energy-- how is energy technology different than, say, software? Than, say, iPhone app? Obeida? Do you want to take a shot?

AUDIENCE: It's more of you have to build your products [INAUDIBLE].

BOB DIMATTEO: Yeah.

AUDIENCE: You need the materials to build your products.

BOB DIMATTEO: Yeah.

AUDIENCE: More capital for startup [INAUDIBLE] from your own company.

BOB DIMATTEO: Right. Exactly. Yeah. And so there was a recent book written called *Lean Startup.* And so this-- the following is basically a plug for the engineering field, a plug for what many of you were doing. So this book called *Lean Startup*-- and the folks at HBS and Sloan are very much aware of it, et cetera.

But it turns out that it's been kind of a hit and almost sort of a craze in the innovation world. But he says in it that he assumes that what they're trying to do can be done.

So in other words, if you're making an app for the iPhone, you know that you can actually produce it. It can actually do the thing. Do you do it this way for this market? Do you do it this way for this market? And that's where the war gets lost or won in that world.

But here in energy, it's really not that way because there's no guarantee that things can be done. Like we've seen billions of dollars go into the liquid biofuels-- which one of you guys mentioned-- recently. And it's turned out that it's very hard to do-- very hard to do. So it really it was a technical impediment, which is dramatically different than, say, if you're in the software world, where you basically know that you can build what you want to build.

And so whether you're think about starting your own businesses or whether you're interacting with management in some big business, that understanding of applying the right questions know and the right rules-- so if you're in an energy business, you probably want the engineers to be more involved in management decisions than maybe if you were doing software or something. What you really need to know is, it's the marketing people that need to drive-- that need to drive the process. OK.

RICHARD SCHMALENSEE: Questions? Reactions? More about his life story?

BOB DIMATTEO: So we-- just to finish, we developed this for about six years-- excuse me. We developed this for 10 years at Draper Lab, literally across the street.

RICHARD SCHMALENSEE: Government funded?

BOB DIMATTEO: It was about half internal and half government. And from starting with just an idea, like you guys have mentioned some ideas, and then analysis, and quickly moving on to actually building hardware-- tiny hardware with just scientific proof of concept demonstration hardware. And then scaling up to the kinds of panels and modules that you see us working on now.

The last five years of that work, I went on in the startup, MTPV Corporation, which got spun out of Draper. I came back here for a year as a Sloan Fellow-- plug for the Sloan Fellows program. And actually, the first couple of million dollars, roughly, invested in our company was from fellow Sloan Fellows, which was pretty remarkable.

RICHARD SCHMALENSEE: Draper Labs also have-- do they have that IP?

BOB DIMATTEO: Yes. Yes. Draper Labs involved as well.

RICHARD SCHMALENSEE: And did they give you the IP or do they have the IP?

BOB DIMATTEO: I actually had the IP here. And so it went with me to there and then beyond. That was kind of part of the original-- another important person at MIT whose name is Robert Rines-- none of you probably had the pleasure of taking his course. He kind of taught one of the-- the first course probably for engineers in innovation.

Now all you guys know about entrepreneurship and innovation. Some of you are smart enough to realize that entrepreneurship and innovation isn't right for everybody at every moment, and it can be very painful along the way. And I'm happy to talk about some of that if you want. And if you were smart, you would ask me about some of that if you want, especially the half of you thinking about starting businesses.

And but anyway, Robert Rines-- so he taught a course-- it was taught out of course 6, I'm not sure why for starting like 50 years ago in innovation and patents. And I took that course. And he became our patent attorney for MTPV Corporation until he passed away a couple of years ago.

So MIT is really all over this technology. And I guess-- Hiram said, you know, you should tell them that you think that you guys have the potential to get to 60% efficiency and like a megawatt per square meter. And I hate talking about those things-- it really is what keeps us going.

I mean, these initial niche markets, they don't keep you going. They keep you focused so you know what you need to do when you get up every day. But they don't keep you going. What keeps you going is a larger vision about something that-- it doesn't have to be as large as producing 50% of the world's energy. But it's a larger vision as to how what you're working on creates meaning.

RICHARD SCHMALENSEE: One of the things I hear you saying-- I hear in your narrative and that I hear from a lot of entrepreneurs-- and, in fact, a lot of people, but a lot of entrepreneurs in particular is your path has not been a straight line.

BOB DIMATTEO: Certainly.

RICHARD SCHMALENSEE: And if you sort of sit there-- sit out there and think, I'm going to do this, then I'm going to do this, then I'm going to do that, then I'm going to do that-- it sort of worked for Bill Gates, but it doesn't work very often. It doesn't work very often.

BOB DIMATTEO: Right. And not in the energy field, it seems.

RICHARD SCHMALENSEE: Yeah.

BOB DIMATTEO: Is it possible there are some fields where it does sort of go more linearly? Like I don't know, maybe biotech and drug discovery and something like that?

RICHARD SCHMALENSEE: Oh, no.

BOB DIMATTEO: No?

RICHARD SCHMALENSEE: But I mean for individual careers.

BOB DIMATTEO: For individual careers, OK.

RICHARD SCHMALENSEE: Individual careers, if you're going to be an entrepreneur, a lot of people-- I was with this startup and it failed, and I worked with this company. And then I did this, and then three of us had this idea. And you don't sit here at 20, 21 years of age and you see that path.

BOB DIMATTEO: True. Yeah.

RICHARD SCHMALENSEE: The path opens up in front of you.

BOB DIMATTEO: Yeah. Oftentimes true. And it's why there's a lot of merit in starting a career in existing companies. Because as the young man pointed out, you do get lots of experience and knowledge that addresses those kinds of dilemmas and risk, et cetera.

RICHARD SCHMALENSEE: Questions? You want to hear about the pain? Ready to hear about the pain? Give them a little pain.

BOB DIMATTEO: Well, I'll invite my wife in to give you the pain, right? Yeah. So when you're with startups and you're getting them funded, that can be challenging, right? So have any of you funded anything to date? You know, even like lawnmower business when you were a kid, you bought the lawnmower? Yes, over there.

AUDIENCE: Like raise funding for something?

BOB DIMATTEO: Yeah.

AUDIENCE: Yeah. I'm doing a project this summer in Africa. And we have to raise a little less than a thousand dollars to join the project. So that's an initiative from the companies to sponsor us themselves.

BOB DIMATTEO: Yeah. So where are you in that process?

AUDIENCE: Excuse me? Where are we?

BOB DIMATTEO: Yeah. In the fundraising process. Money's in the bank? Talking to--

AUDIENCE: Yeah. we're just-- we recently [INAUDIBLE].

BOB DIMATTEO: Congratulations.

RICHARD SCHMALENSEE: Nice.

BOB DIMATTEO: That's a real big deal. Yeah. And what are you doing in your Africa?

AUDIENCE: Will you be able to transfer it, are you actually going to transfer it?

[LAUGHTER]

AUDIENCE: I'm hoping we'll see something soon.

BOB DIMATTEO: OK.

AUDIENCE: You will, I'm sure.

BOB DIMATTEO: Well, that's an important point to be at. The final little legal details, and the little words and everything else, that can take a while. It can take a while for the money to actually show up in the bank. So you can't count on it until it's actually there. But sounds like you guys are very close. Congratulations. What are you doing?

AUDIENCE: Well, we're launching a robotics league.

BOB DIMATTEO: Robotics league? In which country?

AUDIENCE: Nigeria.

BOB DIMATTEO: Nigeria. Very cool. Wow. Was there another hand? Yes?

AUDIENCE: I raised funds for a high-school business that I started.

BOB DIMATTEO: Really

AUDIENCE: Yeah. Is was basically just selling greeting cards to corporations. And we raised money by allowing people to buy shares in the company because we decided to liquidate it at the end of the year, so we raised $600.

BOB DIMATTEO: Excellent.

AUDIENCE: That was all we needed.

BOB DIMATTEO: OK, so you get two real entrepreneurs here.

RICHARD SCHMALENSEE: Asking people for money is an interesting experience.

BOB DIMATTEO: Absolutely. Yeah. Absolutely.

RICHARD SCHMALENSEE: OK. Any other questions? I did promise you sort of a half an hour or something completely different, so we'll do that. Thank you.

BOB DIMATTEO: Great. Thank you.

[APPLAUSE]

Thank you all. Pleasure speaking with you.

RICHARD SCHMALENSEE: So to compromise between those who wanted that talk and those who wanted this talk, I'll give you a little bit of what I would have tried to make an hour and a half out of if you had voted for economic development and green growth.

This story starts in '87 with the Brundtland Report, a Commission chaired by Gro Harlem Brundtland, a woman who was a former prime minister of Norway, that coined the phrase sustainable development and gave it the definition that you see there.

And in that first small bullet is sort of the economist's interpretation. And that is the economy has a certain set of assets, intellectual capital, and physical capital, and the environment, and the natural world, a set of stocks. And the notion is you should pass on to be sustainable a set of stocks that are as desirable as the set you inherited. The first President Bush called that stewardship. Since he was a Republican, nobody used that term. But that's the concept, that you have a certain set of assets.

So you could say, for instance, that economic development in 19th century Britain was arguably sustainable, right? They burned all the coal, the country was dirty as anything for decades, but they came out of it with tangible capital, intellectual capital, a whole set of other assets that provided standard of living.

Saudi Arabia is mostly spending the oil money on consumption. So when the oil goes-- British coal is long gone, but Britain used it. And the issue is that when the Saudi oil is gone, that generation is not going to have the assets.

Now it's a little vague, right? It doesn't distinguish between intellectual capital and species. And it doesn't say anything about poverty. And this question of the future generations' own needs-- I mean, if the future generation wants to only play video games, then wiping out the elephants won't matter. But if future generations actually care a lot about the natural world, then having great video games is not very important.

So if you don't know what their needs are, it's a little tough. And you know I was once interviewed and asked what I thought sustainable development meant, and I gave the Brundtland definition. And they said, is that all, you mean? That's kind of narrow.

And I said, what do you mean? They said, what about sustainable communities, and sustainable lifestyles, and sustainable-- it's gotten to mean sort of everything that's good and wholesome and green-- and a little vague. But nonetheless, start with the sustainable development notion.

The next big event was the 1992 Conference on Environment and Development. This was the conference that led to the Framework Convention on Climate Change and really started that conversation-- the Kyoto Protocol and all of that. That was a big deal.

172 governments participated. 108 heads of state or heads of government went. That's huge. And what came out of it was a lot of paper. But the Framework Convention on Climate Change, which really structured all the subsequent debate.

So now we come to 20 years later. And you've got this whole UN machinery. And we ought to have a conference Rio+20. Well, if the headline was climate in 1992, the question is, what's the headline now? And that leads to the green growth discussion, right?

So you began to get-- beginning a few years ago, you began to see staff papers emerging talking about the green economy, and green development, and green growth. Now I have to say, I've read a lot of this and the definition is not entirely clear. It is described as a subset of sustainable development.

And it seems to be that subset of sustainable development strategies that doesn't involve degradation of the natural environment on the way. So the British development wouldn't be-- might be sustainable because at the end of all that dirt, they had high living standards and the prospect of higher living standards, but not green, because the environment was degraded rather substantially. It recovered, but it was degraded substantially in the process, and I'm sure species were extinguished.

So maybe you could do fossil fuels and be green. I think so. But if you think about alternative ways of doing sustainable development, there's another-- another part of the World Bank-- the World Bank, the UN, the OECD, and others are talking about green economy. If you go on the World Bank website and you look carefully, you see papers on inclusive growth.

And that says, well, you have to be sustainable, but you should focus on poverty. Green growth says, you ought to be sustainable but you should focus on the environment. OK. Where do you go from there?

Well, this is what is sort of the interesting thing. Particularly the UN now argues that if you make very large investments in going green, growth of living standards will increase. The phrase that's used is, "a new engine of growth."

Now if you're a cynical economist, you realize that not only does that mean there's a free lunch, but one we'd all be paid to eat, right? Going green will raise living standards after a very short period of time. So what I want to do is talk a little bit about that.

You can imagine how I and others got engaged. This was sort of very-- if you don't know this world, the World Bank and the OECD and the UN have a lot of-- not to insult anybody, but they have a lot of very smart people without much to do. So a lot of papers generated, and mostly, people pay little attention to it.

But suddenly-- and I'll get into specifics-- suddenly, you have these organizations revving up for a big world conference talking about-- talking about massive changes in investment strategy. And I'll give you a sense of it. So economists have begun to write about this.

What's on the reading list-- What's on Stellar is a couple of the shorter I think World Bank and-- I don't remember whether it's UN or OECD publications-- piece of mine commenting on this whole thing that's-- it'll be the introduction to a special issue of *Energy Economics.* And then some other papers that I want to talk about, about some of the issues.

So let me talk about just some of the issues here. One issue that everybody points out is absolutely right. GDP doesn't pick this up. GDP-- we talk about stocks and flows, you have family silver, you sell the family silver, you have a party, the party shows up in GDP. The fact that somehow the silver's out of your hands-- or it shows up in sort of your consumption, certainly.

If you burn down-- and there are plenty of African countries, plenty of other countries, that have basically burned down-- New Hampshire did it, Vermont did it-- you burn down the forest to fuel economic development. There's a sense in which you're changing one asset to another. Certainly, just looking at what gets produced understates the cost.

So if you look at net national product which gets depreciation of some assets, it subtracts from gross national product. It picks up some of this, but properly measured, you'd want to take into account the fact that what happened in 19th century Britain was they paid for economic development in part by trashing the environment, in part by killing people with the health effects of all that smoke, and degrading the natural environment.

So you'd want to take that into account when you said, what's income, what are living standards, really? We don't know how to do that. There's work at the UN, there's work at the US.

But part of the green growth argument could be that what you want to measure isn't GDP growth, but growth in living standards, taking into account all this other stuff, taking into account changes in health, taking into account changes in the natural environment, and so forth.

So you could say, OK, that's a relevant point. Another relevant point is they talk about increasing investment, taking 2% of world GDP and investing it in green things. Well, if you make massive investments and they're not terrible, they will eventually raise growth, right?

So you're increasing-- there are numbers in my paper. They don't matter. But it's basically what the UN is saying is the world as a whole needs to make a massive increase in green investments. If you do that, you probably will raise growth. That doesn't mean it's a good idea.

If you doubled the US capital formation, you'd raise us growth. A, how do you do it? B, is it actually a good deal? But the kicker here, most of these models say, here's how we raise growth. We raise growth by reducing environmental limits on growth.

What would environmental limits be? Well, in the limit, everybody gets sick and production and productivity falls off. So if you've ever tried to breathe in large Chinese cities, you get a sense that there is some theoretical-- that this may be more than theory in some places at some times. But globally, probably not.

So two good points and one point that's sort of OK in theory. The good points are-- in terms of going green-- that GDP growth isn't really a good measure of growth in standards of living. It isn't a good measure of sustainability, period-- sure.

Increasing the rate of investment in green technologies and lots of other things will raise growth. Yeah. So would investment in railroads, so so would investment in highways, so would investments in education. But that's certainly true.

It is possible that one way going green increases economic growth is by sort of reducing environmental limits. The soil's exhausted, the people are sick, et cetera, et cetera, the aquifers are depleted, and you're stuck. That is certainly possible.

And if you're really a pessimistic person, you can look down the road, and climate change is another set of mechanisms that could do this. But is it globally quantitatively important in the near term? No evidence. OK.

More relevant points. Certainly in rich countries, you can make the argument that, yes, we should be greener than we are, particularly in this country. If you think carbon dioxide does anything, it probably makes sense to switch-- that understates the case to switch to less carbon-intensive growth paths, cut emissions, conservation, shift to natural gas.

The interesting question, and the politically tricky question, is in poor countries. Because the green growth story is a story not about the rich countries, it's a story about mostly poor countries-- massive investments in going green in poor countries.

Well, massive investments in almost anything sensible in poor countries would be a good thing. Where does it come from? Probably doesn't come internally. This is the climate problem revisited in a way-- probably doesn't come internally because they don't have it and they have other priorities. Again, telling the Chinese not to use the coal while so many millions of people live in poverty is a tough point, tough sale.

Massive foreign aid? Well, appropriating massive foreign aid-- again, there's some numbers in my paper, about $400 billion a year from the US. Imagine walking into Congress and saying, yes, yes. I know we have problems but we need to send $400 billion a year in foreign aid. You would not get a vote on the floor. You would not get a vote in a committee.

And the other problem is the history says, if you dump lots of foreign aid on countries that don't have good governance structures, you don't get good results. It gets stolen. It gets wasted. So that's not likely.

So without the aid, how can you possibly, say, in Africa, in particular, where there is hydro potential, where there is coal, and where there is a lot of poverty, why not use it? Now you can say-- you could say-- actually, that's wrong. You can say the equity issues are absolutely clear. We talked about this when we talked about climate change.

If I'm a poor country and you say to me, we really need you to go green. I would say to you, you didn't. You got rich. You burned your coal. You cut down your trees. Why can't I? If you give me money, maybe I won't. But maybe if you give me money, I'll waste it. It'll go to a bank account in Switzerland or the Cayman Islands. Or I'll hire my brother-in-law to build a dam.

So this is sort of a terrible thing. Now this is something that's sort of not on, as the English say. There's just no way to get it done without massive transfers of aid, and there's no way to get the massive transfers of aid done-- as far as I can tell, in any case.

One point I do want to make, though, and that is while you're thinking about startups, one of the really interesting opportunities globally is the large number of people who have no electricity, period. Who are off-grid, who are in rural areas.

And that's one of those interesting bottom-of-the-pyramid opportunities that a lot of people have tried to crack because having lighting at night makes a huge difference. It means kids can stay in school. It means the family can work after the sun goes down at various things. But in particular, kids can study.

And there are a lot of people who have tried to crack that economically. Usually some version of solar plus storage deployed at the community level or solar lanterns that could be sold cheaply and charged in the daytime and used at night. So there are lots of opportunities there. It isn't massive. It isn't massive.

The other thing to point out is one of the real tragedies here, and one of the reasons why the whole green growth notion is compelling, but painful. And that is, again, there's a piece on Stellar-- if you ask who's going to be harmed by climate change, it's mostly the developing world, right? I mean, we can afford to build a wall around Manhattan to deal with sea level rise. Bangladesh can't build a wall.

But of course, the developing world is also driving climate change if you look at the growth in emissions, as we talked about on several occasions. There's just no obvious fix. So the green growth is trying to-- is an attempt by a whole set of staff people to advocate for massive change in the way the world runs that's probably not going to work-- not going to work politically, which is one reason why I didn't feel like doing an hour and a half on it, because I think the air has gone out.

There will be a circus in Rio. There will probably be 100 heads of state or government in Rio next month. I'm told hotel rooms are going for thousands of a night, so it will be a big circus. I'm told that the official US government position is that Rio should produce a clean five-page statement of principles and policies, and that the current working draft is 260 pages long.

Diplomats do this. Diplomats do this. So this is the story of people trying to figure out what comes after the Framework Convention on Climate Change, what comes after thinking about sustainability. And the answer is-- or was-- a major push toward being green, please, really a serious, major push. I think it lacks intellectual foundation, I think it lacks political foundation. I think it will be much discussed at Rio and nothing will happen.

I do hate the last talk to be so cynical. Maybe we'll be hopeful next week when we hear your papers. Do you have questions or comments on any of this? That's sort of the-- this is the current diplomatic state of play. This is an attempt to do climate by the back door and call it green. It isn't going to work, sadly, I think. Yeah, Julien?

AUDIENCE: I was just curious if you expected anything like productive at all to come out of it?

RICHARD SCHMALENSEE: Well, you know, diplomacy is a really strange process. It's easy to mock, right? Because particularly in climate, there's this group of diplomats that like to get together every couple of years and talk and make progress. But without government support, it's all just talk.

Given that the main problem the world sees right now is slow recovery from a deep recession, and given the current state of politics in the US on climate, I expect lovely prose to come out of this. There might be agreement on something small. They might get something on forests. I could give you my cynical lecture about forest protection sometime.

As long as you don't affect the demand for wood-- protecting this forest doesn't reduce the amount of wood cut. But that's just the economist. I expect there will be some agreements. I don't think they will be very important. And as I say, I expect a circus.

The folks in the diplomatic community would say that's too cynical. Even just talking with the whole world involved, putting a spotlight on these issues, keeping up pressure of some international kind on governments that don't want to act helps. Sort of the water on a stone view of the world.

That's what they do. And every so often, there will be a chance. You'll get the Montreal-- you'll get the Montreal Protocol on ozone depleting gases because that process had started. Those meetings were being held. New science came, the structure was in place, the support mobilized, bang. We got a very constructive international agreement.

It isn't going to happen here because the preconditions aren't there. But the water will drip on the stone. The water will drip on the stone. Rory?

AUDIENCE: Has anyone-- well, [INAUDIBLE] response to-- he was saying, the rich world didn't follow a green growth path, but they followed the greenest growth path available to them at the time within economics. And you could argue that Britain, if they could have, Britain wouldn't have covered all their cities in smog and soot. But they couldn't. The growth is good for its own sake.

RICHARD SCHMALENSEE: Yeah. That's a decent debating point. But you also say, when did the rich world begin to take the environment seriously? And when did it begin to have any impact on policy? And that's sort of '60s, '70s, right? You don't see much-- you don't see much conscious thinking about it.

The big US event was DDT and Rachel Carson's *Silent Spring,* which was-- do you remember? '57? '62? Around there-- around there. Birds were dying because DDT was making their shells too thin and they couldn't reproduce. That was like oh my God, our chemicals are actually doing something out there.

But to most people, better things through better living through chemistry. So to argue that we were doing the best we could is to argue that we were doing it unconsciously. And that may be true, but it's not-- that's not that persuasive. It's a good shot, though.

Anything else? Anything else on your minds? Feeling ready for the quiz on Wednesday? You were brilliantly reviewed on Friday. Ready to go? OK. Off we go.