PROFESSOR: Today we're going to dive into Cost, Price, Markets, and Support Mechanisms. The support mechanisms otherwise known as subsidies.

So this is Lecture 18. We're approaching the end of our course, actually. We have about, we have a handful of lectures left, and then we go our separate ways.

This particular lecture will be followed up not this Thursday but the following Thursday. We'll have a guest speaker come in and talk about the cost model that he's developed for PV into a very high level of detail, so it'll be a lot of fun. And you'll be able to use that cost model to model your own PV devices, apparatus, and so forth.

Next Tuesday, a week from today, we'll be touring a PV facility. It'll be here on campus to make it easy for everybody. We'll go over to the student center and tour the PV system up on the roof there, as well the balance of system components. So we'll be able to have a close-up look at how that works.

But today, cost, price, markets, and subsidies. We want to talk about those items because, at the end of the day, PV is a product that is competing against bulk electricity. And if we can't compete against the bulk electricity, then our on-grid applications are going to be rather limited. So we want to understand how all this works and fits together.

I'll be providing you several snapshots and several pieces of the puzzle with a lot of discussion back and forth over the course of today's lecture.

First off, let's dive into PV cost and price. What is the difference between cost and price? They're used interchangeably in colloquial language, but there's a big difference. Jessica?

AUDIENCE: Cost might be what it costs the manufacturer, and price is what it's sold at [INAUDIBLE].

PROFESSOR: Absolutely. So cost is what it actually costs to make, to manufacture, and price is what people are willing to pay for it, what the market is demanding. So sometimes price can be above costs-- you're hopefully in that situation most of the time-- and sometimes price can actually be low cost.

What is an example of when price could be below cost?

AUDIENCE: The Amazon Kindle?

PROFESSOR: The Amazon Kindle? Why would it be doing that?

AUDIENCE: Because they want get people to adopt the device and then make money on subscriptions to books or [INAUDIBLE].

PROFESSOR: Hm. A loss leader, right? Something like, for example, if you buy your razor handle, and that's really cheap, but then they gouge you on blades. Or other examples include the cheap items in the front of a store. You walk inside the store, and then you're barraged by all the more expensive ones right inside. So loss leading can be one example of price below cost.

Another? Other examples?

What if I start making a gizmo, and I pocket an enormous profit. And all of you start watching me make that gizmo and say, hey, I can do that. It's pretty simple. It doesn't take a rocket scientist to manufacturer that gizmo. I can do it too.

And everybody starts manufacturing gizmos. Pretty soon, we overwhelm the demand, at least at that given price point, and the price is depressed as we enter a price war. We enter what is called an oversupply condition. That's another example where price can fall below cost.

And another reason why price can fall below cost is simply the price, or the market you're trying to address, simply won't buy your product at that cost. And that's the case with substitution economics. If we're competing against fossil fuel-based electricity, let's say, and we want to compete against that, we might not be able to manufacture solar panels cheap enough to address certain markets.

For example, Wyoming, which has $0.05 per kilowatt hour electricity due to cheap fossil fuel. The southeast of the United States as well, where the TVA, the Tennessee Valley Authority, has very low-priced nuclear and coal power.

So these are examples of where price might be below cost.

We're going to get more into that over the course of today's lecture, because there are some very interesting geopolitical debates occurring right now. Oftentimes the two sides are very staunch in their positions and there isn't much nuance, there isn't much shade of gray, there aren't many rational arguments presented. And instead, we're going to be diving into some of that, discussing the nuance over today's lecture.

Let's dive into cost first up. This is a paper that I presented already in class. I've also steered some of the project groups toward it.

This is a proceeding back in-- whoa. This wasn't 2009. My apologies. This is 2003.

This was presented at the 3rd World Conference of Photovoltaic Energy Conversion by Tom Surek, presenting a very simple cost model, if you will, for PV, more specifically the impact of efficiency on cost. And by no means was this the first time that something like this had ever been presented, but it was a nice summary of the work to date, highlighting several, I would say, key levers, cost levers.

Efficiency-- that's the solar conversion efficiency.

Processing costs-- that's the materials and processing costs for the module in dollars per meter squared.

The manufacturing yield-- that means out of, say, 100 cells into your manufacturing line, how many make it through to the other side without breaking or being discarded due to manufacturing defects?

Capital equipment cost-- that's depreciated over several years, meaning you buy equipment up front, but then due to financial gimmicks, you're allowed to allow that cost to hit your books over an extended period of time, not all at once upfront.

Overhead, and so forth-- overhead being the health insurance, if it is paid to the workers, and, of course, R&D and the CEO's salary, and so forth could be lumped in.

So this is a very simple way of estimating cost. It's a linear equation, a direct relationship. What is, I would say, the economics, or a more sophisticated way of looking at cost?

Other than just saying it's the dollars per watt-peak, you would look at it in terms of cents per kilowatt hour. Right? You would look at it in terms of, how much do you pay for your electricity coming out of the wall? Or in this case, out of the panels?

What would factor in to what is called the levelized cost of electricity, when you're actually calculating cents per kilowatt hour? How would you convert dollars per watt-peak-- OK, I know how many dollars it took to manufacture this. I can also depreciate my equipment costs over several years to manufacture this.

How would I go from dollars per watt-peak into cents per kilowatt hour? We all agree that cents per kilowatt hours is the metric of importance, right? That's what we pay on our electricity bills, or at least some of us do.

So when we pay our electricity bills, we're paying in cents per kilowatt hour from the grid. And when we manufacture our solar panels, we pay in dollars per watt-peak.

Let's start simple. Why is dollars per watt-peak at all useful? It's so far removed from cents per kilowatt hour that it almost seems an artificial metric. Why, again, do we use dollars per watt-peak? Jessie?

AUDIENCE: Because most coal-based or most fossil fuel-based electricity is based on a capacity factor, which is measured in kilowatts.

PROFESSOR: That's a good way of looking at it. And then the capacity factor of solar would be based on what? On the solar resource locally, right? And that might vary from location to location.

OK. So what dollars per watt-peak allows you to do is, given a rated nameplate capacity, you can calculate, based on the solar resource locally, how much energy will be produced over a certain period of time. And then from that, you can calculate your cents per kilowatt hour, because now we're converting from power, or rated nameplate power, into energy, which we can use, and which has economic value.

So there is a rationale, then, for giving nameplate capacity in terms of watt-peak. In other words, rating a factory in terms of megawatts per year or gigawatts per year produced. That means that each module that goes on to the cell tester is rated, and there's an estimate based on the cumulative module production what the total watt-peak output of that factory was.

And then depending on where those modules go in the world, they might produce different amounts of energy. If you take those same models and install them in Alaska or Arizona, you're going to get widely varying energy outputs.

OK. So then, how do we transition? We have the dollars per watt-peak. We have to know the local solar insulation that would allow us to calculate what the cents per kilowatt hour would be, assuming a certain cost of capital. We have to buy those panels up front. You have to buy from me a huge number of panels, which are going to last for 20, 25 years. I'll guarantee it.

But you have to front that money up front, which means that you need to lend that money from a bank or from a financial institution, and then you'll be paying a certain amount of interest every year. And it's the spread, it's the difference between the interest payments and the money saved that's going to turn your profit.

And that's what's called the rate of return of your investment. And there's also a payback period, or a monetary payback period, over which you're not going to be making money on average, but after the payback period is finished, then your solar array will be a money press. It'll be printing money.

And so over the entire lifetime of the investment, you can calculate an average rate of return.

OK. So given that setup, we're going to be talking about some incentive mechanisms and, today, really, really simple cost model. More on Thursday when we get back to this, how we calculate cost in a more sophisticated manner.

I want to introduce this concept very simply at first, just because there are some parameters here in the sensitivity analysis that overwhelm all the others. And they can be very simply seen an equation like that right up there. And one of them is efficiency. The processing costs also matter quite a bit.

OK. Inside of processing costs, you also have labor and commodity materials. And those can vary significantly from region to region.

There are a number of assessments out there. I'm going to be leading us into the current big debate which has exploded in Washington DC, the case of Solyndra, and then SolarWorld filing the complaint with the US Commerce Department.

I'll be easing us into this whole question of US and foreign manufacturing, using that more as a hook to get us interested in the overall topics of the day. And then toward the end, hopefully you'll be able to see, with more shades of gray, what exactly is going on and perhaps formulate opinions of your own.

So where is PV cost actually at? Where do the current cost numbers currently stand? It is extremely difficult to get at true cost. Price? Price is easy. You go out there, probe the market, see what people are willing to sell panels at, maybe send a few emails to a few companies saying, hey, I want to install 100 of your panels. How much are you willing to sell them to me?

This is what people do. They probe the market. They test it. So price is fairly easy to gauge.

But manufacturing cost? If I go up to you and say, hey, can you tell me how much it costs to manufacture panels in your factory? Would you be willing to give me that information? They'd probably say no. Probably say no. Definitely to me, as a professor. Maybe you as students, they might show you a little bit more of how it actually works under the hood, since many people believe in the educational mission.

But, by and large, people are fairly secretive about this, because they realize that their stock price is heavily dependent on market perception. And if I go out there and write an article and say, hey, your company produces panels at twice the cost of yours, investors are going to flee your company, especially if it comes out of a university like MIT.

And so there are big repercussions associated with the divulgation of cost numbers, and that's why it's very hard to get to the bottom of it.

What you find most often are aggregators. These are consultancies that work with several companies. They may be, for example, photon consulting across the river in Boston. It might be Greentech Media consulting branch, which is located here in Cambridge, Massachusetts.

There are many consulting companies, and several of them based here in the Boston area. And these consulting companies work with several PV manufacturers and, over time, begin aggregating data and presenting market trends, generalized market trends. A few of them single out specific companies, but most of them just aggregate the data and present general trends.

I presented to you this, a few articles as of late. These are relatively recent-- within the last three to four years-- and because there has been so much change over the last three to four years within the PV market, even an article three years ago is highly outdated.

So you'll want information that's within the last year if you're going to be using cost and price information for your projects. Even within the last few months. And if any of you have any doubts in that regard, you can come talk to me.

So the fully loaded module manufacturing cost is shown here. An estimate, again. An aggregation based on access to multiple companies' data. Polysilicon-- this, of course, being crystalline silicon technology, which accounts for about 85% of the current market.

Polysilicon in blue, depreciation in red. What's depreciation?

AUDIENCE: Is that the discounting of the capital that we just talked about?

PROFESSOR: Exactly. Exactly. So what that means is, I borrow a lot of money to manufacture these panels, to buy the equipment, to buy the factory and set everything up. And then I have to pay interest on my loans. I have to pay interest on the loans, and what I do is, I start writing off the equipment as a loss to the company.

So that equipment is going to be useful over a certain period of time, and then we can assume that it's outdated and that I'll need to buy the next generation of manufacturing equipment. So I can begin writing off the value of that equipment over a certain schedule, over a certain period of years. Five, seven, depending on the company, depending on the way they're-- I don't want to say cooking their books, but the way they're manipulating the numbers in the accounting sector.

So the depreciation varies. And it varies because the interest rate at which you acquire the loan, and the interest rate-- or the inflation rate of the particular currency in question, is different in different regions. So when you're calculating depreciation both of those things matter, and that's why those numbers can vary from place to place.

Materials. Materials cost. These are the materials used to manufacture the module, typically called commodity materials. You would look at them as the extruded aluminum components, the glass in the front side, the encapsulant materials, and so forth. All the fancy stuff that we saw when we visited Fraunhofer last week.

Let's see what else. We have labor. That's pretty straightforward to see. If we're manufacturing in China, we are looking at a labor rate, could be as low-- base labor without adding housing and so forth-- the base labor rate could be as low as $2.75 an hour in US dollars. And in US dollars in the United States, we could be looking at labor rates of somewhere in the range of $16 an hour before you start adding in Social Security and benefits and so forth.

And there may be different levels of automation in the two different places, which shifts costs from labor into capital equipment. So if you realize that you have a much higher labor cost, you might want to buy more robots to do the manufacturing.

And vice versa, if you're in China and you realize, oh my goodness, our labor rates are increasing almost exponentially, definitely super linearly with time. As the country takes off and there is inflation, wage inflation, a company that is trying to project forward five or seven years might say, well goodness, it doesn't make sense for me to flood my manufacturing line with people right now, because that manufacturing line still has to make a profit in five years.

And so I'm going to buy more robots now. Even though I might not need it today, I might need in five years. And so there's a bit of risk calculation that gets thrown into this as well.

Utilities and overhead. That's pretty straightforward. For looking at utilities, that means the electricity, mostly, to run the lines. It could also be water which is used in the manufacturing process.

Note the caveats in several of these studies, especially the one out of Lawrence Berkeley National Laboratory. Manufacturing cost, you can do a number of things with that. You can assume that you're buying your polysilicon, you're buying the polysilicon, manufacturing cells, modules, and systems.

Or you can assume that you're buying the cells, and the cells are commodity products equal in price throughout the world, and that you're just manufacturing the modules. So you can cut costs in many different ways, depending on what assumptions you make.

The price of the cell on the international market may be very different than the cost to manufacture that cell in your particular country. And cost is almost one of those things that you can torture until it tells you the story you want it to tell.

It's one of those things where, if you did these numbers a little bit differently and said, OK, we're buying cells and just making modules, and then adding shipment fees-- let's say transport fees from China to the United States-- China and US might look almost equal.

Whereas if you integrate over the entire supply chain and say, OK, I'm going to be manufacturing my polysilicon, then my wafers, then my cells, and finally the modules, then you might start seeing some disparity based on these other parameters shown here.

The point being, be careful when you see a cost assessment. Probe their base assumptions and try to understand what their biases and motivations were for presenting that particular comparison. Especially nowadays, where you have more and more parties with vested interests in presenting one story or another. We'll get to that in a few slides.

Experience learning curve. Now we're getting into price. We're venturing beyond cost and into the regime of price, which is definitely more easily measurable. And that's why we have some fairly good data going back several decades.

And you can see here, this is cumulative sales in gigawatt peak. That means the cumulative number of widgets, in, this case, watt-peaks, produced by solar industries worldwide. And this is a global average module selling price. Not the system, the module. So not the balance of system installation, labor, and so forth, but just the manufacturing of the module.

And what we can see here is a general trend over time with a decreasing price. That's good. Sorry, decreasing price with time. That's excellent.

What is that called? This curve here, plotted in a log-log scale, where you have a line through the cumulative manufacturing production versus price. What is that curve called?

AUDIENCE: Is it an experience learning curve?

PROFESSOR: It's an experience learning curve. And you'll get something similar for any high-tech product-- computers, toasters-- as long as the product isn't changing significantly with time.

And even sometimes if they are, as is the case with the solar panel. Solar panels back in the 1960s, or the 1970s, rather, looked very different than the solar panels today in terms of the materials and the processes used.

And it all falls along this very interesting experience learning curve. So it's extremely tempting to say, oh well, what price do we need to reach to be cost competitive-- or competitive, let's say, with bulk electricity? We need to reach a price of, say, $0.50 per watt-peak? Oh, easy. We'll just project forward and we'll see how much cumulative production is needed, and then we'll subsidize until we get to that cumulative production. And bingo, voila, it'll happen by magic.

Well, the reality is that each little bump here along the learning curve was some-- if you look closely, you can kind of see these little bumps here. There were many traumatic events within the industry that forced people to innovate, to produce better technology, whether it's the technology itself, something designed here in the laboratory at MIT or Harvard, or whether it's something innovated on the manufacturing line where they realized, oh, this is a more efficient way of manufacturing the solar panels. It's cheaper.

This little bump right here, boom. This represents a period in which prices actually went back up year in and year out. What could cause prices to go up? What are some of the motivations for that? I mean, scale's increasing. The market's growing. It's not shrinking at all. It's not like the points went back here as they went up.

So the market continued to grow, the manufacturing capacity continued to grow, but the price went back up. What could have caused that?

AUDIENCE: Demand outpaces supply?

PROFESSOR: Demand outpaces supply. Exactly. So in this specific case, what happened was the polysilicon feedstock, which is the input material into this entire process, was in short supply. It takes about, in those days it took about 24 to 36 months to get a new plant online. Long lead time and billions of dollars of investment.

And so the polysilicon suppliers didn't really want to invest unless they knew photovoltaics was for real. And the PV industry had exhausted the elasticity of the supply market in the polysilicon business.

And polysilicon suppliers looked at the situation and said, well, let's let prices go up a little bit. It can't hurt us too bad. We've been starved for several years because of low polysilicon feedstock prices. Let's let this increased demand kind of push prices up a little bit before we really decide what to do.

And by the time they decided what to do, there was a lot of them getting in the market all at once, which had this effect. Boom. Now, it's not only the polysilicon, but also the cell manufacturers, the wafer manufacturers, that expanded their capacity during this time between 2007 and 2010.

Now today's most recent price point, as I saw it on one of our more trusted websites, put us down at around $1.03, $1.05 per watt-peak. So we're down here. We're well below the historical average trend. We're in an oversupply condition right now.

Why did the oversupply condition come about? Well, partly because of this undersupply condition, many people saw an opportunity and said, well, we can address that demand. We can grow in this industry right here.

To grow in the industry, you need capital. You need access to finances to expand. What happened in 2008 in Western countries-- and 2008 was more or less when it really hit the fan, if you will, in the United States in particular. What happened in the capital markets?

AUDIENCE: Capital was severely restricted becase we're not providing a lot bones.

PROFESSOR: Exactly. We had the financial crisis here in the US. So in the United States, there was a pull back of lending. The government stepped in shortly thereafter, realizing that this was going to be an issue. There was the ARRA.

Does anybody know what that is? It's not the American Association of Retired People. This is very different. ARRA is the American Recovery and Reinvestment Act, right? This was the Stimulus Act. And this act actually did inject a lot of money, or a lot of capital, into renewable energy projects that began hitting in sometime between 2009, let's say, at the beginning, until 2011. In this period right over here.

Anybody hear of the word Solyndra? Yeah? You've heard about it? Solyndra was one of the companies that received funding under the ARRA, or "arra." Under the Stimulus Act.

So a lot of interesting things were happening during this brief little period right here. During the mid 2000s, China was getting a lot of bad rap by environmental groups, and the United States as well, for its growing greenhouse gas emissions. There was a growing concern over greenhouse gases culminating in the Copenhagen Discussions, that countries, especially developing countries, had to do more to reduce their greenhouse gas production. And this, of course, invited a wonderful tug of war between a developing country bloc-- the most progressive of the developing countries, let's say, normally described as BRICO, so Brazil, Russia, India, China, and other, including South Africa-- and the developed countries.

And you can see perspectives from both, and it's wonderful. The sophistication of that debate in terms of poli-sci arguments was just beautiful to watch. On one hand you had the developing countries that said, well, wait a second. You folks in the developed world, you used a lot of fossil fuels. And the majority of the CO2 emissions that have occurred to date were from developed countries, today.

So it's a bit unfair that you're asking us to reduce our CO2 intensity, because that might hamper our own development. Why don't you pay reparations for the CO_2 that you've already emitted and help us decrease our CO_2 intensity?

So there were these beautiful arguments being constructed on both sides of the debate. What China decided to do-- so on the international spectrum, not much happened. And that's fairly-- sadly, it's fairly typical of most of today's-- I'd say the larger the body happens to be, whether it's the federal government or the world institutions, it seems that things happen at a much slower pace the larger the entity is.

But at a smaller entity, for example, the state level, which we'll see in a few slides, in the United States, a lot's happening right now. And within China's central government, a lot happened in response to some of that criticism. They said well, there's a point. More a point that fossil fuel emissions really decreases our quality of life.

If you look at some of the pollution in our cities, that's not very becoming. We can do better. And furthermore, we can create jobs for the people who are flooding our cities from the countryside looking for economic opportunity.

We can create new jobs in this industry. And we'll do it by making capital available to this new nascent industry at a time when it's very difficult to achieve capital or acquire capital in the West, in Europe and the United States.

And so that's again happening really in the mid 2000s. And what we'll see in a few slides is the massive growth of the Chinese manufacturing market in response to the availability of capital in those countries.

Let me go back to a slide that I presented, I think it was lecture number 1, where we looked at the cumulative production of PV as a function of year. And if we plot this on the log-linear plot, we can read the growth rate off of the slope of that curve.

So this was somewhere around 10%, 40%, maybe upwards to 60%, depending on what data points you include in those lines.

Interestingly, back in 1990, if we look at the distribution of different technologies, multicrystalline silicon was 1/3, single-crystalline silicon about 1/3, and thin-film technology, namely, pushed by amorphous silicon, was about 1/3 of all manufacturing production.

As the market evolved-- sorry about this. There we go. So again, the different technologies, just to situate ourselves, single-crystalline, multicrystalline, and thin films. As the market evolved going into the 2000s, we saw this type of breakdown occur.

We have silicon, or crystalline silicon comprising around 85% to 90% of the market, and thin films not growing as fast as crystalline silicon. It was still growing. The market overall is going gangbusters, but crystalline silicon technology was going faster than the others.

And in part, this was due to the fact that crystalline silicon technology was a bit cheaper than thin films at the time, largely driven by the efficiency parameter that we've just seen in the previous slides. And turnkey equipment was available.

So if you had capital someplace in the world, anywhere in the world, and the labor and commodities were such that you could compete in the market, and the shipping costs weren't extremely prohibitive to get your product to the most interesting markets in the world, you could compete because you could buy turnkey equipment.

Even if you knew nothing about how to manufacture a solar cell, knew nothing about semiconductors or solid-state physics, what we've discussed here in this class, you could still go out and buy a turnkey manufacturing line and get technicians to come in and teach you how to manufacture solar cells. That was the beauty of these equipment companies.

And so the equipment companies specialized in crystalline silicon technologies. And as such, many of the turnkey lines that grew up out of Greenfield factories, especially in China, Taiwan, and other places around the world, leveraged these turnkey manufacturers to a great extent.

So price, markets, and subsidies. We're going to be looking at-- it's a bit of a hodgepodge in the sense, if we're addressing cost, price, and manufacturing all together in one big stew, I think that's useful because the three are interrelated. A price is difficult to set without a cost, and the manufacturing is part of that story and can help us tease apart what exactly is going on right now with Solyndra, with SolarWorld, and so forth.

OK. So let's start with customer needs. Just to acquaint ourselves, if we're talking about price, we can't divorce price from our customer. And in terms of what our customer needs are, we have on-grid applications. That's represented by, for example, a solar system on my house, on the student center. These are systems that are tied to the grid and using the grid as a battery to store the excess energy.

Off-grid, this represents, for example, the Lighting Africa project here within our class. These are folks who don't have access to an electrical grid and who need to have that electricity there. So while people on the grid are worried about cents per kilowatt hour, people off the grid might be worried about the dollars per hour of light. That might be their metric of merit.

So from the customer's perspective, what is their value? What do they get from the solar PV system on the roof? These parameters under here, underneath each of the pictures, represent the value parameter. And again, it's a very cartoonish way of thinking about it.

It's a lot more complex when you start getting into the weeds and figure out what the customer actually wants. Reliability factors in, access to the product, repair, reliability, and so forth, factor in as well. There are many factors that add in to value.

But what we've done here is emphasize the biggest levers, if you will, and some of the biggest differences between different applications of PV. If you're looking at the solar panels on top of the Toyota Prius, you might not really care about the cents per kilowatt hour, because you're paying $20,000 for your car, so what's a few extra dollars here or there?

But you might care about the watts per meter squared, which is really an efficiency parameter. You might want it to satisfy a certain function that it could not do otherwise if the panel was too low efficiency.

If you're sending something into outer space, again, you might not care about the manufacturing cost of the panel, , because the shipment costs, in other words, putting it onto the rocket and sending it up in outer space, is $10,000 per kilogram. You might be more worried about, how much does it weigh? What is the specific power of the solar panels?

Likewise, if you're installing them in a big-box company, for example at Walmart or Kmart, and you have a big flat roof that isn't very strong, isn't well reinforced, you might care about that parameter as well, or the grams per meter squared. I'm sure that factors in somewhere. Actually, it doesn't.

So there are many other parameters that could matter for a particular application. Dollars per meter squared for aesthetics for a building integrated system. I've had architects come to me and say, can you make a yellow solar panel? I'd really like a yellow solar panel.

And here I am thinking of the solar spectrum and seeing the biggest, the peak of the solar spectrum being reflected away from the panel into the observer's eye, and I'm thinking, well, I can make it kind of dark yellow, yellowish. OK. How much are you willing to pay?

And there are many different parameters here that matter for the customer.

This one right here is a concentrator system, so you have these optics that concentrate the light into a small little spot, and they're looking at the watts per millimeter squared. A very small device, how much power does it output? The cost of the actual device is almost irrelevant. It's the power output that matters, because the majority of the cost is sunk in all the commodity materials around it.

All right. So we're getting into this because we're going to focus largely on on-grid applications, and I'm going to explain to you why. If you're in the Lighting Africa project, you probably care mostly about that. But the on-grid applications currently comprise 95% of the current market.

Substitution economics. We're substituting PV with, or we're substituting fossil fuel-based power, on average in the United States, somewhere around 600 grams of CO_2 per kilowatt hour. We're substituting that with PV which is on the order of a factor of 5 to 20 lower.

So what types of grid electricity will PV substitute? What does this mean for traditional generation companies, also called gencos? And what is a fair selling price for PV electricity? Very interesting questions.

So in terms of markets, this is just a breakdown of off-grid consumer applications and on-grid. When I first got into this, somewhere around here, it was broken down about 50-50, PV on-grid and off-grid.

Today, much further down, off-grid applications, probably below 10%. I don't know the precise numbers for you, but it's stayed relatively flat compared to the growth rate of the on-grid. And the reasons for this, we'll see in a couple of slides.

This is the value of PV electricity, per a 2008 report. If you look at what is easily monetized-- easily monetized depending on the policy in a particular case-- you have the cost of fuel, the cost of capital, typically for a power plant, the CO_2 emissions offset.

This is if you have a price of carbon. Notice how small it actually is, leading a lot of people to conclude that maybe carbon pricing isn't the biggest lever for bringing PV onto the grid. That's a whole other discussion. We can have that later.

Grid losses. These are the transmission and distribution losses, the difference between having the PV mounted or distributed, the power generation source mounted right on the site of use, as opposed to a centralized location that has to distribute it.

These are much more difficult to monetize. And you can add in here health impacts related to emissions, and so forth.

You're looking at the security, the reduced risk of having a product producing electricity at a certain known price for 20 years. You're also looking at tax bonuses. These are tricky because tax policy can change. You're looking at uncertainty in your raw feedstock material, the fuel.

And the need for backup is something that reduces the value of PV electricity. If you, at some point in the future, will need to back up PV power with something that is more dispatchable and it's still an uncertainty in the power grid, that's something that is reducing the value of installing the PV today.

Some might argue that that $0.01 negative is actually a drastic underestimation of the risk associated with backup power needs.

But this is a fair look at what the so-called true value of PV electricity might be, which would lead us into pricing. If we know the value, we can enter pricing.

And not many people can argue with this, because this is substitution economics. This is just saying, OK, how much does it cost to produce fossil fuel electricity? And let's substitute that.

Anything over here in the yellow is what people might say, well gee, if we really look at the true price, or the true cost of fossil fuels, this is what it really costs if we take away all of the subsidies and add in all of the externalities. What's an externality? What's an externality mean? Yeah?

AUDIENCE: Is it when the consumer isn't aware of something that the [INAUDIBLE] is doing?

PROFESSOR: Yeah. So when the consumer-- or let's put it this way. When the true impact, price impact, is not factored into the selling price. Let's say-- hm.

Let's say that I sell you a miracle drug. And it allows you to be 5 times more productive than you are right now. But then every time you have your needs, down the toilet goes a bunch of chemicals that the water plant now needs to filter out, and the water plant begins failing some of its standard tests when they measure water quality.

So they add in some more filters into their system. They figure out how to get rid of this compound. And now all of the water treatment facilities around the country begin adding in these new filters, and it costs somewhere on the order of $1 billion.

That is an externality. That's something that wasn't factored into the price of selling you that miracle drug that allowed you to be 5 times more productive. It's an example of how everybody pays for the acts or the purchases of a few.

And that's the case with energy production as well. So it's difficult to argue in economic terms-- or it's difficult to put a specific price on externalities, because these could be things like premature deaths. And there are statisticians who will calculate the number of people who die prematurely as a result of exposure to mercury or cadmium or some other emission coming off of a fossil fuel-burning plant.

But then how do you monetize that? You have to assign a value to a human life and say that a certain economic value was lost, both in terms of productivity cost, but also in terms of the investment due to that person dying. And they do that. In government, there is a value to a human life, and it can vary somewhat from one group to another.

But it's very difficult to price in externalities. And that's why oftentimes these things in yellow here are neglected or not considered. For the purposes of today's discussion, we're just going to factor in mostly these parameters right here because we have a greater hold on them.

So in terms of PV installations worldwide cumulative, I want to compare and contrast where our customers are versus where our manufacturing is. And we'll get to some really interesting questions associated with that.

So look at that. Where would you expect PV to be installed? You'd expect it to be installed in the sunniest places. Why? Because the amount of energy produced is related, proportional, to the amount of solar resource that's available in that spot.

But from a customer's point of view, solar resource isn't everything. They're also looking at the cost of displacement. What is the price of electricity I'm paying? And how much of that can I displace with my PV electricity?

So there's some more sophisticated concern here. And further, the price of electricity might not only be dictated by the true cost of production of the fossil fuel power plants. There may be a few governments out there that say, well, look at all these externalities. We want to begin factoring those in. We want to provide an incentive for people to produce PV electricity.

That's commonly referred to as a subsidy. So if we look at the total installation, EU is really leading the charge here. And we saw on those installation maps, there's not a heck of a lot of sun there in the EU. Germany has a solar radiance similar to what we have here in the northeast of the country. And we know that most of the PV installed in the United States is going into the southwest.

Japan, rest of world, USA, a relatively small fraction up there in China. Tiny, tiny little bleep. China's the peach one right up there at the top.

So I would say less than 5% of total installed worldwide. Actually this is 1.5%. You can read it off right here, the division.

OK. So we have a very interesting perspective here about our customers. This is a breakdown, again, in terms of customers again. A little bit better detail. Instead of just seeing EU, we're looking at a variety of different customers.

And this is new installations worldwide. So if, for example, this blue bar goes down, it just means we installed less PV this year than we did last year. It doesn't mean that the total amount on the grid went down. It's just new PV installs.

So the blue down here is now Germany. We have these countries that are like flashes in the pan. Italy, for example-- sorry, Spain. This one, Spain, grew up really quick and then disappeared. Italy grew up really quick and then is shrinking. If we extended out to 2011, it would be back to a very small amount.

We have USA that's consistently growing. That's a nice healthy market. In Germany, that's growing as well.

Wow. What an interesting dynamic. Why did Spain have this flash in the pan and then shrink suddenly? What did they do differently than Germany did?

We'll start asking those questions and answering them in a few slides.

If you really want to get detailed information about the US, where PV is installed in the United States, one of your MIT colleagues and a bunch of NREL folks got together and put up this beautiful archive, if you will, compendex of as many PV installations as they possibly could in the United States.

So that's the website. Unfortunately, I didn't include it in your slides, so you might want to write that down if you're curious about it. Wonderful resource. Again, NREL, National Renewable Energy Laboratory based in Golden, Colorado. And you can see the install distribution throughout the United States.

Again, a bias toward states that have high electricity prices, like New York and Massachusetts, and lots of sun, like Arizona. The price of electricity is rather low in Arizona. It's below $0.10 per kilowatt hour, but the amount of sun available is very high. Whereas California has both.

OK. So we talked about the customer. Now here we're talking about the manufacturers. So we have the customers, the demand; the manufacturers, the supply. Obviously, the manufacturers are growing at the same rate as our customers are installing. Even faster, mind you. Inventory rates are almost, somewhere between 25% and 50% nowadays. So the production has grown faster than the demand has, at least at current prices.

What we've done right here, or what is done right here is a normalization by market share, just to demonstrate how the market dynamics are changing as the industry grows. So from 2005 to 2009, this doesn't mean that the industry stayed flat. It continued growing at a breakneck pace, but the countries which comprise the manufacturers have changed significantly.

So let's look at Europe first off. Europe pretty much started really feeling it during the financial crisis. They couldn't keep expanding in 2008, and then when prices really started to drop, 2009, as we saw, they didn't continue expanding. Were a bit uncompetitive.

US, shown here in the green, again, dropping. India, I guess sort of growing now. It's definitely on the upswing.

Japan decreased considerably, considerably. During the 1990s and the early 2000s, Japan had the largest solar company in the world, Sharp, better known for microelectronics that you might find around your house. Somehow, some way, the executives at Sharp saw this coming. Saw a huge rise in demand coming from Europe, and ramped up capacity in Japan.

And when they did that, they were able to address large portions of that. They made a healthy profit for several years, and then they just stopped expanding in PV. Part of it might have been they saw the market dynamics changing.

They saw their costs, their manufacturing costs, relative to, for example, China-- this is the orange right here-- and Taiwan, above China, above the orange-- and comprised today-- this is 2009 numbers, if we fast-forward to today in 2011, China and Taiwan comprise 55% to 60% of the PV industry worldwide. Production, manufacturing, production.

So what does that mean? Let's explore together some of the interesting results of that. Let's look at some of the good things. What are some of the good things about production going to China and Taiwan from, say, Europe and the United States, of solar panels? Let's look at that for a second.

So we'll look at the glass half full perspective. What are some of the good things?

AUDIENCE: It's more likely that these developing countries will use solar panels?

PROFESSOR: More likely that the developing countries will use solar panels? Was that the case over here? Not really. It's going. It's going. OK. I suppose, if the technology's available there. Maybe the technology isn't quite cost competitive with local electricity yet, so there's isn't that demand pull locally.

Maybe the realization is that, well, goodness, we can address this European market. They're willing to pay a lot more for the panels than we are, so we might as well export right now. But at some point in the future we might be able to satisfy internal demand. Yeah.

And there are gigawatt plants, PV installs going up in China right now. In part due to increased electricity demand, in part due to weakened demand elsewhere in the world, and a very large manufacturing base in China that has to put their panels out somewhere. So there is, yes, adoption. I'll cede that point. Yeah?

AUDIENCE: Lower cost to the consumer?

PROFESSOR: Lower cost to the consumer, yeah. So in the United States, if you look at the price of installing a PV system in the United States, the price of installing the PV system is around $5.20 on your roof today. The cost of buying the module is around $1.03, $1.05, from China. And so that means that 80% of the profit margin right now is being gobbled up by a US company.

The price came down-- let's see, when I installed the panels on my roof, I got a little bit of a better deal. But I would say the average price for a PV system in 2007 must've been somewhere around $8 per watt-peak. And now the price is down at around $5.20.

That said, in Europe, in Germany, which has 10 times more installed PV than the US does, the price of installing a PV system on your roof could be below 3 euros per watt-peak. So the price is lower because the profit margin that the installers are getting right now is smaller.

So yes, absolutely. Lower cost product in US markets. That isn't the whole story about what you're going to pay, because there's still the installer that's stuck in between the Chinese manufacturer of the module and you serving as the middle person. Providing you value, still, but still extracting a very large profit right now, a disproportionately large profit, shall I say.

What are some of the other good things. Yeah?

AUDIENCE: If cost in big markets is reduced, then that could lead to more market penetration, and then the [INAUDIBLE] adopted more, and even if prices go up, it might maintain [INAUDIBLE].

PROFESSOR: Yeah. And so what you're leading to here is really what the demand curve of PV looks like. And in the past, if you look at what people are willing to pay for PV, let's say-- let's convert it into dollars per watt-peak, since that's the universal unit of PV cost. And this is the, let's call it total market size in terms of watt-peak, and this being a very, very large number.

What you can do to-- first order. Just how would we construct the demand curve for the United States for PV. How would we go about doing that? How much are people willing to pay for their PV modules to offset the cost of electricity?

Well, to do it right, we need the levelized cost of electricity analysis. We'd assume we're borrowing money from the bank and do those fancy economics that involve something to the power of something, and that being the interest rate, and then we calculate it through. Just a first order. Hand-wavy Mickey-Mousey.

We might take into consideration the manufacturing cost of the module. Sorry. Back up one step. We might take into consideration the cents per kilowatt hour of the electricity that we're getting from the grid and the insulation, the solar resource, that is available at that particular location.

So if we have data granular to the state level of the price of electricity on average throughout the state, and the solar resource availability on average throughout the state, we can immediately comprise 150 markets in the US. Residential, commercial, industrial for 50 states.

And then we'll have a demand curve, a very simple one, for how much people are willing to pay for their PV electricity. And it looks more or less like this, if you start working it out. Rough sketch. Rough sketch.

This is Hawaii. Those poor critters over there, although they have beautiful sun and enjoy a wonderful life, they're paying a lot for their energy, because they're on a few rocks out there. They have no natural resource under the ground to speak of, except geothermal, I suppose. But they're shipping in a lot of their fuel.

That's why if you've ever gone to Hawaii and rented a car, you are surprised at the sticker shock when you go off to the gas station and try to refuel.

Their price of electricity is about $0.30 per kilowatt hour residential. But it's a very, very tiny market. So you're not going to be able to satisfy much demand. You're not going to be able to produce too many panels there.

You start having interesting things happen when you start hitting the bigger markets, like the tiers four and five of California, Texas, New York. These are big markets that have a lot of people in them, and they have larger electricity prices and/or large solar resource available there.

And so at some point, the demand curve reaches these plateaus, where if you decrease the price even a little bit, of a sudden, voom, the amount of market you can address for this amount of price decrease, the amount of market that you can address is huge.

And so the slope of this line, the slope of the demand curve, is indicative of what happens when you reduce your price just a little bit. And so yes, producing cheaper panels, when you start hitting these plateaus, can result in massive, massive demand pull, or market pull. So that's another good reason to have cheap panels.

Let's look at the flip side. What would be some of the downsides, let's say, to module manufacturing going into China? You can assume anything is on the table. CO2 emissions, jobs, et cetera. Let's start teasing into some of those questions and looking at some data. I might flip back and forth during the presentation if we have to address specific topics.

AUDIENCE: Bad politics if American photovoltaic manufacturers fail, and it reflects poorly on the industry and the American political scene and decreases support for that.

PROFESSOR: Yeah. So bad politics. In DC, this is often referred to as the optics of the situation. How people observe, or how people perceive something.

The litmus test is not DC itself. I was down there on Thursday, and everybody in the solar space was-- I think it was Wednesday and Thursday, yeah. Everybody in solar space was freaking out about a particular event that was going on in Capitol Hill.

I was telling folks, don't worry. It's not going to-- I mean, in terms of the rest of the country and the perception of the rest of the country, it won't be that significant. And I'm sure Secretary Chu will do a phenomenal job up there in front of the congressional panel. He did phenomenal.

And so people were really, really worried about something that didn't have too big of an effect outside. Granted, what people should be worried about is the impact, for example, that desequestration of the discretionary funds will have on R&D once they start kicking in in 2013.

If you mandate a reduced funding level for funding agencies, you will have an impact, and a long-term one, for that matter.

So the optics of the situation. There has been a slight decrease in public support, I believe on the order of 5% to 10% since the beginning of the whole Solyndra affair, support for solar renewables. But the support remains high, and still continues to be high among Republicans and Democrats alike. Especially when compared to, say, congressional approval ratings.

But let's not look down. Let's compare ourselves to higher.

What else? What are some of the potential negatives? Let me start guiding you, because you hear so much about bad this-- jobs, whatever.

Let me guide you into some of the questions you might not have thought of. There is a colleague of ours here at MIT, Tim Gutowski's group, that is looking into matters concerning manufacturing of PV and installation of PV from a CO_2 perspective.

So if you manufacture your PV in a coal-rich country that is spewing out emissions into the air, you are going to have a greater CO_2 intensity per kilowatt hour of energy that the panels will produce over their lifetime than if the panels were produced, say, in a country that has a large abundance of hydropower or geothermal. Or, hey, even produces solar panels using other solar panels. That'd be nice.

But in the growth situation where solar is rising, or the manufacturing capacity is rising at 60% a year, it's a little bit unfeasible to think that solar will power itself forward. It almost violates one of the laws of thermodynamics.

So we look at the CO_2 balance, right? We think about, gee, what if we were to be smart about where we manufacture and install PV? Then it might make more sense to manufacture PV, say, in Norway, which is based on hydropower, and install them in China, which is largely running on coal.

So from the CO_2, from the global carbon perspective, again, these are externalities that aren't being priced in. OK? CO_2 and-- yeah. Go ahead, please.

AUDIENCE: But wouldn't they actually be priced in Norway, because they are in the new emissions trading scene? I mean, they're not priced in China, but the cost of electricity in Norway doesn't [INAUDIBLE].

PROFESSOR: Yeah. So point conceded. In certain countries, some of the externalities are factored in. Not, perhaps, at the levels they should be, but some are factored in, whereas in other countries, they're not at all.

So we have what is referred to in some terms as an uneven playing field in the sense that in some places there are regulations in place that increase the price of electricity, whereas they aren't present in other places. And in some cases, they work to your advantage, like in Norway, for instance, or Switzerland. Big hydro countries.

What are some other potential disadvantages? You hear a lot about jobs, jobs moving overseas. Let's start looking at some of the numbers next Thursday, when we have Doug coming in here and talking about the cost model.

A good number to keep in mind, a good number to keep in mind for the manufacturing of modules-- so back to this part right over here-- for the module itself, typical numbers would be 2 to 12 people, depending on what region of the world you're in, 2 to 12 people per megawatt.

So if you have a total market of, say, 10 gigawatts-- it's larger than that. We'll do quick math. So if it's-- the megawatt would be 20,000 people per gigawatt, about 10 gigawatts, somewhere in that range, on the low end. And on the high end it would be somewhere around 200,000 people per gigawatt, on the high end of the labor intensity.

So the high end of the labor intensity represents a company like Trina Solar in China that is extremely labor intensive. It's located in Changzhou. It's on the high-speed rail between Shanghai and Nanjing.

The low end of that scale would be more representative of, say, Suntech, which is almost next door in Wuxi, which has adopted a different approach, saying, we're going to invest in robots because we're uncertain about where the whole labor thing is going to go in China, where the prices are going to go.

Or REC, which is a Norwegian company, but they opened a factory in Singapore, which has very, very low labor rates, because they invested a lot of money in capital equipment, in robots to move modules around their factories.

US, if you can look at turnkey manufacturing lines, are typically round 3, 3.5 people per megawatt. Those are some good numbers to keep in mind.

So when anybody comes to you and says, jobs, solar jobs, with these sorts of numbers you can begin estimating, OK, give me a number. How big is the solar market going to grow to? What is the level of automation? What is the labor intensity of manufacturing of the modules? And you can make an estimate on the total number of jobs, direct jobs, direct jobs associated with the module manufacturing.

Then there are all the indirect jobs as well. There are all the people supplying the commodity materials into your manufacturing line. There all the people who are working as administrative assistants and R&D staff and so forth.

So it's not quite as simple as that, but it gives you a number to really start grabbing. And that, of course, doesn't include all the installations, installer jobs.

All right. So we're talking about grid-tied electricity. I'd like to move on to our next few topics here. We're talking about grid-tied electricity. This is-- ooh, it's in German. Sorry about that. This is over a period-- "tag der woche" means "day of the week."

And this is basically the peak power in gigawatts, instantaneous at any given point. So we have morning, middle of the day, night, middle of the day, night. There's a little bump right here during prime time TV.

And we have the output of PV going from 5 gigawatt peak to 30 gigawatt peak, you can see, beginning to eat into the profits, essentially the peak hours.

So let me differentiate between base load and peak. Base load power would be voom, right? Something providing a constant power output as a function of time, something like a nuclear power plant, coal fired power plant.

Peakers would be natural gas fired power plants that receive the call. It's like, Jessica, you're in charge of the peaker over there. Based on my weather report today, I'm going to need so many gigawatts tomorrow between the hours of 10:00 and 12:00. You think you can turn yourself on then? I'll pay this amount. Yep. Jessica's going to battle. Yes, I can do that.

PV, on the other hand, is coming on if the sun's coming on. And to date, there isn't a great degree of predictability. We can see if that's going to change, based on one of our class projects here. But there wasn't a great degree of predictability.

You can see here, for example, and here varying amounts of sunlight from one day to the other as a result of changing insulation.

There's, of course, changing demand as a day of the week goes by. On Saturday and Sunday there's less demand for electricity.

So what PV is doing is eating into some of the highest-use periods, which is good from the market's perspective-- from the, shall we say, the "person in charge of maintaining grid stabilities" perspective, because they want power to be produced then. They don't want to run out of generation capacity. And PV is avoiding the situation, or at least prolonging the situation a few more years, until we run out of power generation capacity on the grid.

As our population grows and our energy intensity grows, we're needing more and more power, but we're not building new power plants at that rate, generally, in Germany and the United States. And so PV is helping to defray some of that deferred investment in new generation capacity. So that's good.

On the bad side, somebody who has invested-- let's say Mary's invested in a natural gas generation plant. She put the money down for Jessica's plant. Jessica's running it. And now Mary realizes, well goodness, I thought I was going to get a steady rate of return over 20 years from my natural gas fired power plant.

That rate of return was factored into my economic analysis when they borrowed money at a certain rate from a bank, and now you're telling me that this upstart technology, this new PV stuff, is coming online and is going to take away some of my profit. That doesn't work for me.

As a matter of fact, on peak days in Bavaria, which is the southeastern part of Germany, today PV can comprise as much as 40% of electricity on the grid during peak hours during the summer. And what that does sometimes is force conventional electricity producers to either turn off or go into negative pricing, meaning they shunt the power to ground so that they don't have to pay to put their electricity on the grid.

So that's an interesting market dynamic that's evolving as more and more PV electricity enters the grid in these regions of high penetration, which include California, Hawaii-- the island of Lanai, I believe, has up to 40% as well on weekdays. Bavaria in Germany, which is the southeastern part of Germany.

Let me get to this point right here. Predicting where the market will go, we talked about the demand curve for PV, and we collapsed both insulation and price of electricity from the grid into this dollars per watt-peak figure, which is how much people are willing to pay.

We can also break it out into annual solar energy yield. This is the solar resource available. It's using the units of kilowatt hours per kilowatt peak, meaning the number of kilowatt hours, the amount of energy, that a unit of rated power, kilowatt peak, of the solar panel is going to produce. So how much energy will a unit of solar panel produce? That's down here. And of course, larger amounts mean more sun, more solar resource.

On the ordinate, we have average power price of household. This is US dollars. It should be average electricity price, US dollars per kilowatt hour. So that's how much people are paying for the electricity, what you're displacing.

And you can see that these little bubbles here represent the size of the market. So as the price of PV electricity comes down, we are able to address more and more markets. As the subsidization of PV electricity increases, you move these little bubble up.

And as the subsidization comes back down, the market pull-- not the manufacturing subsidies but the use or installation subsidies-- as they come back down, the little bubbles move down, and eventually rest at their so-called true market price without the externalities factored in.

And so you can see how we're beginning to enter a regime where PV is starting to look interesting in a lot of places. And as we begin addressing these markets, or hitting these markets, you can imagine two Gaussian curves intersecting, one being the price of PV electricity, the other being the price of grid electricity, as they intersect and overlap. You expect an exponential growth, and that's what we're seeing in the market today. Question?

AUDIENCE: What is the California [INAUDIBLE] for tier 4 and tier 5?

PROFESSOR: Yeah. So California decided to implement more of a-- well, it is a little bit regressive in that sense. But what they did is, they said let's, instead of paying the same price for electricity for everybody-- which actually it would be even the opposite way.

You know how residential, we typically pay higher rates than industrial? That's because industrial buys in bulk. They buy electricity Costco size. We just buy it corner-store size. And so they pay less for their electricity. And California realized this and said, well, this is a perverse incentive.

What this does is it gives an incentive to people to use more electricity. Because if you buy in Costco size, you pay less per kilowatt hour than if you buy in the corner store. Instead, what we're going to do is reverse that incentive by penalizing the people who buy more electricity, so your rate is going to be higher then if you just bought a small amount.

So what they did is, the government bureaucrats got together with some of the scholars and decided, these are reasonable amounts for a residential house to consume. This is the next tier up, this is the next tier up, this is next tier up, and this is completely unreasonable.

And so what they did is they tiered their electricity. And you have California tiers 1, 2, and 3 represented by the big bubble, and tier 4 and tier 5 as represented at higher pricing. So if you happen to fall into the tier 5 category, you could be paying upward of $0.30 per kilowatt hour for your electricity.

And it's a way of penalizing you for powering two swimming pools in your backyard along with, I don't know, something in the range of 10 kilowatts of lighting inside of your house. Whereas, if you're running on a meager budget, you might do much better. Do you have a question over here?

AUDIENCE: Is it only residential?

PROFESSOR: California's tier 1, 2, 3, and 4, and 5? That a great question. Joe, would you happen to know if commercial and industrial fall into tiers as well, or if it's just residential?

AUDIENCE: My guess would be no, because that would be political suicide.

PROFESSOR: Well, even the residential is political suicide.

AUDIENCE: Yeah. The residential system is actually kind of a bad one, because if you have like eight people living in a house versus two, it doesn't take that into account. So it's not a per capita thing. [INAUDIBLE].

PROFESSOR: So many states and countries have tried to adjust incentive mechanisms. And I'm not sure specifically about the commercial and industrial. You might want to jot it down and give a quick Google search after.

Germany. Growing gangbusters. The market versus time. This is installed capacity annually versus year. And again, subsidies, support mechanisms, tax breaks, incentives.

What we wanted to emphasize here was that Germany is not one of the sunnier places in the world. Look at this. It's almost half of the modulus installed, and yet it has less insulation than even here in the US northeast. Even the sunniest places in Germany. This is Bavaria. This is the place that hits 40% of electricity on peak summer days coming from PV.

And this is where we are, right up there. Same scale. So something's going on in Germany, and it's not sun.

The German government instituted a number of-- this little D represents Deutschland, Germany-- implemented a number of incentive programs to increase the amount of PV installed on the grid, under the assumption that if they had demand pull, they would have a supply push. Meaning, they would start up local industries.

Initially it didn't quite take off as fast as they hoped, so they began providing direct manufacturing support, direct subsidies to install PV manufacturing plants, to the point where they were willing to pay $0.50 on the euro for each piece of capital equipment that moved in on German soil to produce plants in the mid 2000s.

So that combination of events left them with a booming market, upwards of 100,000 jobs, I believe, in Germany related to PV manufacturing, and a lot of PV installed on their grid as a result of the market pull.

So really, when it comes to subsidies and support, you have to decouple what is market pull, which means we want PV installed on our grid to offset our country's carbon emissions, versus manufacturing push, which is to say, you want to set up a factory in my country? Fine. Come right in. I'll provide you the finances. I'll provide you a lower cost of capital on your loan, or help you by providing a direct grant or loan.

And these are two different support mechanisms, and that's why you see that dichotomy between Germany, which installs a lot of PV and has a decent amount of manufacturing; the US, which has a lot of installation but not a whole lot of manufacturing traditionally, although it's changed, the support has changed over the last three years; and China, which has a heck of a lot of manufacturing but not a whole lot of local demand. It's because each country has adopted a different approach based on optimization of different functions.

In terms of where a lot has happened on the state level, these are RPS, renewable portfolio standard, policies with solar and distributed generation provisions distributed throughout the United States. And you can see that the states have picked up where the federal government lacked in terms of leadership.

In terms of getting PV on the grid, the states really pulled hard. In, specifically, New Jersey-- some really oddball states, like New Jersey here, installing about 5 gigawatts of solar. California had another more of a market pull mechanism.

Rebate programs for renewables, this is if you install solar panels you might get a few thousand dollars back from the state government. And it just gives you a sense of how the states have filled in that void where the federal government didn't step in.

And this has come, in part, to our detriment. It's nice, because we can allow-- the federalist approach allows individual states to say, hey, we prioritize green jobs. All right. Let's support it. Let's make it happen. And that's certainly Massachusetts' take. California, Texas, certain other states throughout the US, including Mississippi most recently.

But the downside of that is that you have each state doing its own thing, each municipality, each local electric utility grid doing its own thing. And what can happen is diversification of support mechanisms and incentives to the point now that if you want to install panels on your roof in the United States, there over 18,000 ways you could do it within the US alone.

18,000 unique types of paperwork that you have to fill out, depending on where you are in the United States. In Germany, you have one unified paperwork for the entire country, and it's very short. I believe it's two pages. And in the United States, you can fill out a few reams of paper.

One of our friends in California once estimated it takes about $1 a watt to fill out paperwork and to get certifications and so forth. Maybe it was a little bit of an exaggeration, but the price is high.

And so recently the DOE has attempted to address this as well by fostering a "race to the top" type incentive mechanism for states to facilitate installation.

But still, in Massachusetts, we had-- remember for the system on my roof, we had at least two inspectors come by from different agencies. That could have been consolidated into one.

So while state independence is good, and local utility independence is great, from the perspective that the federal government is lacking in terms of moving forward, the states can push forward at their comfortable speed. On the downside, it makes it very difficult for an installer company to reduce its costs because it has to address a multitude of local markets throughout the US. And that adds to cost.

In terms of projections, I really hesitate. Because in 2006, there were a number projections of where we'd be in 2010, and many of them-- you can see the range here, going from 4 gigawatts up to, actually, I think Photon Consulting had us close to 30 gigawatts back in 2010. Photon Consulting was closer to right than most of the other groups, interestingly. The 4 gigawatts was obviously pretty far off.

So projections are very dangerous because you could be easily wrong. This is just to show you an example.

These are projections of where the solar market is going to go. From the EPIA, which is the European Photovoltaics Industry Association, it's one of the better sources that I could find with the various scenarios giving you an indication, a tornado plot, if you will, of where the market is going to head over the future.

And the bottom line is that most likely it will continue to grow. Even though it's going to enter a difficult year, a difficult two years as the oversupply condition works itself out of the market, we're headed for some pretty massive growth.

And just keep those numbers in mind. If this grows up to be, say, a 100-gigawatt industry, and there's two people per megawatt, that's 200,000 people employed just in the manufacturing of modules. Not counting all the other people on top of that, maybe another order of magnitude, if we use the car industry as an example.

So we could be looking at two million jobs worldwide. And where they are, who works on them, how the value chain is distributed between R&D, manufacturing, this is all open. The next decade will decide that. You'll help decide that. So with that message, I let you go.