RICHARD SCHMALENSEE: What I want to do today is look ahead and talk a little bit about where the grid's going. This is going to be based largely on that future of the electric grid study that a bunch of us did. You'll see in the Joskow paper a fair amount of overlap and an awful lot of agreement, although his emphasis is a bit different.

So let me start with what the system looks like now. That's a picture of line losses in transmission and distribution. That's heat, basically waste heat. And that's gone down sharply over time. It floats around 6-7%.

These appear to be in line with line losses in other developed countries, if you make allowance for density. They're higher in Canada and Australia. They're lower in Germany and France because it's more compact countries. But you can put us all more or less on a line.

Reliability is a little tougher. You might ask the question, is the US system more or less reliable than systems elsewhere? And the answer is we don't know because data on reliability and other aspects of performance are terrible in the US.

You might ask why that is? I'll suggest an answer. And it has to do with the structure of regulation. If I measure-- if I use a standard definition of an outage, and I measure how often my customers don't have power, how many outages, how long they last, and you do the same, and I'm above you in outages, people yell at me. If nobody knows, nobody yells at me.

These things are just not measured in the US. I mean, they're measured in some states. They're not reported in some states where they're measured. And different definitions are used all over the country.

There is now a standard IEEE definition for outages. And it's spreading slowly. But even then, it's not reported in lots of places. So we cannot tell if the system is more or less reliable than it was in 1930, which is bizarre. But there's more.

So I'm going to talk about most of the terrain we covered in the future of the grid. We focused on 2030 because of the speed at which things change, the grid in 2030 will be dominated by technologies we know today. Not necessarily technologies in widespread use, but stuff we know. Stuff we don't know, that's invented tomorrow, is unlikely to penetrate by then.

So we said, what are the big challenges and opportunities? And these are the ones we focused on. There are a bunch of new technologies. Will they get developed and used properly?

There will be more large-scale wind and solar. We'll talk about the issues that raises. There'll be more electric vehicles. How many more, nobody knows. But more, and in some places a fair amount. There'll be more distributed generation, rooftop solar, on various kinds of roofs, and some distributed wind.

And the system will be more reliant on communications and computation, which means there'll be more of an issue of cybersecurity and an issue of information privacy. People will know every 15 minutes how much electricity you're using. And you might not want everybody to know that.

So to remind you of some of the constraints, I talked last time-- last Wednesday-- about the state/federal divide. States are important. There's not much evidence-- not much appetite after the California debacle and after the Lehman crisis-- the whole crisis-- not much appetite for reform.

Very diverse system-- municipal utilities, co-ops, big utilities, little utilities; vertically integrated in some places, federally owned in other places. There's not much growth expected. 7/10 of a percentage point a year is the standard case forecast out to 2035.

And very durable assets. This is actually a number. I had it last year. The forecast number has doubled since last year, but it's still low.

Anybody care to guess what fraction of 2000-- what fraction of-- let's say 2010 capacity will be retired by 2035?

AUDIENCE: 1%.

RICHARD SCHMALENSEE: Well, now you're reaching. No. It's higher than that. It's higher. It's almost 7%.

Last year, it was 3.5%. Last year, the estimate was 3.5%. The difference is mainly environmental retirements and really cheap gas.

So the notion is, because of really cheap gas and tighter environmental policy, 7% of capacity will be retired. That's not a lot of turnover in 25 years. That's not a lot of turnover.

So the generating fleet is going to look a lot like it does now, a lot like it does now. Andrew?

AUDIENCE: This is for a base case assumption, like the--

RICHARD SCHMALENSEE: Yeah.

AUDIENCE: So it has no assumption about environmental regulations or something like that?

RICHARD SCHMALENSEE: No. This is EIA, the Energy Information Administration. And their base case assumes no change in current policy.

So one of the things that it used to assume-- in fact, it does assume-- it assumes that current renewable subsidies, which have-- you don't-- laws don't have infinite lifetimes. The law expires at some point. It assumes that expires.

So it'll be a little light on renewables. They'll run some other cases-- they're not out yet-- assuming more renewables, assuming higher prices and lower prices. But that's the base case. OK, so not much turnover.

the argument is-- that we have made-- is that the grid does have these challenges and opportunities, the turnover is slow. If you want to get anything done in 2035, you've got to start now.

A little bit about the smart grid. And it's not a term I like because it means different things to different people. And here are four examples. This is the National Institute of Standards and Technologies' favorite diagram because-- and it stresses that the grid in the future will have this flow of power, of course-- but lots of flows of data.

And why do they stress that view? Because they're doing this interface standards. They're doing standard setting for all of those flows. That's a big deal.

This is EPRI over here, the Electric Power Research Institute. EPRI's view of the smart grid has to do with things that go-- that happen around the user. So there's some focus-- some automation of the distribution system, and plug-in hybrids, and smart refrigerators, and rooftop solar. They focus on your house.

This is somebody in nature. And in nature, they focus on microgrids. Or in this picture, they focus on microgrids, which we can talk about if you want to. But it's not something that we think is going to be a big deal.

And this is the Department of Energy, which has it all, which has it all. So as the title says, I guess-- my view is that "smart" is a means, not an end. You don't care how smart the grid is. What you care is, what's its performance and what's its cost?

It will get smarter. But that's not the objective. That's the means.

So I went through some of the challenges and constraints. We focused on a bunch of policy areas. So let me talk first about technology. Here I immediately get out of my depth, but I will do what I can.

There's really a lot of interesting stuff. I'm going to talk about phasor measurement units in a few minutes. Flexible AC transmission systems let you vary the characteristics of lines so that you can to some extent control flows. I told you last time that electric power networks are not really like sort of old-style telephone systems or water systems. You don't do valves. You can sort of do valves.

New sensor technologies lets you know the state of the lines. So that on a hot day, you put less electricity through them because you can see they're sagging. And there are a bunch of-- well, dynamic line rating systems deal with automating the readings from these sensors. Energy storage, I'll talk about, and a bunch of other technologies.

Farther on down, toward the customers, the low voltage stuff, there's a lot of automation at the substation that's possible, quicker detection of outages, optimization of-- the Volt/VAR optimization controls-- enables you to control voltage levels, particularly on long lines, more accurately.

Conservation voltage reduction lets you reduce voltage on the whole system just a little bit, to save a lot of energy. There are places where the voltage is above the requirement because you can't properly control it. So it ends-- and you have to keep it above-- you have to keep it within a certain bound everywhere. If you can control better, you can reduce it everywhere.

Automated fault detection is really quite interesting. The interesting part is automatic restoration. Advanced metering systems are very important. And I will talk about those.

And, of course, this all comes together where you control the grid. And I'm going to talk about particularly using these meters in a little while, and right now making the control center work. So here's-- if it works, if it works-- my favorite movie. All right.

I've played this a million times in a million places. And it's never been this bad. Let me tell you what you would have seen if this had worked.

What you would-- this is the result of an outage in southern Florida in 2008. And what you're seeing-- those red dots are phasor measurement units that describe-- that pick up the state of the system in terms of frequency and phase angle of voltage and current, many times a second, time stamped. So that, in principle, they give a picture of the state of the whole system instant by instant, which we do not now have.

The red dots are where the measurements are made. The spaghetti chart on the left is the readings from individual ones. And the folks at Virginia Tech, who invented the measuring systems, have basically interpolated and extrapolated to put together a picture of the whole system.

What's interesting here-- there are a couple of things interesting here. First of all-- and I won't hurt your eyes by playing it again-- what's interesting here is, one, the geographic extent. So if something happens in Florida-- and the frequency distortion most durably is in northern Minnesota or Canada. You may be able to see that.

The second is, it happens fast. This is 25 seconds. So here's where it goes out. Boom. It is happening-- there are things all around the country, all around the Eastern Interconnect, and most durably up there in northern Minnesota.

So it's fast. There's a lot of data. You couldn't react to it as a human. Yeah?

AUDIENCE: Does the setting move?

RICHARD SCHMALENSEE: Well, let me see if I can freeze it.

AUDIENCE: [INAUDIBLE]

RICHARD SCHMALENSEE: It's the extent of the departure. Let me just-- it doesn't want to stop.

Red-- red means, I think, that it's-- yeah. It means it's faster than 60 cycles a second. The frequency locally is higher. Blue means it's slower. So you're getting a-- you're getting a pattern a distortion-- slight distortion-- in system frequency.

Now, in this case, nothing terrible happened. Blackout happened in Florida. Boom. Disturbance propagates throughout the whole Eastern Interconnect within a matter of seconds.

So, A, nobody could respond to that. And nobody looking at the data on-- the graph on the left or the map on the right could think through what to do in time. If there were something serious, that's just too fast with so much data.

So the great thing about these units is they give control systems-- control centers-- a picture of the grid over a wide scale that has never existed before in real time, lots of data. This is just one aspect of it, frequency distortion. But nobody knows what to do with it. There's another picture that is in the movie, which says if you look before the 2000-- when was the last big blackout, 2008-- you see a phase angle change near Cleveland over a period of about 30 seconds and then it breaks.

So if you actually knew what that angle should be, and measured it, and had a monitoring system, you might have been able to tell that the system was about to break. But not everybody that has one of these units actually shares data in real time. We don't have control systems to use the data in real time. The federal government has subsidized putting these boxes out there to measure the system. But we don't have the ability to respond.

I mean, you're sitting there in a control room. You see this thing. Is this a problem, is it not a problem? All of a sudden, frequencies are changing throughout the Eastern Interconnect. Do I need to isolate New England to avoid a blackout up here?

Well, the answer, it turns out was no. But without a lot of automation, you wouldn't be-- and a good model of the system, you wouldn't be able to know that. So moving right along.

So you see the issue that we've got this incredible source of real-time data, with no ability to use it and not much sharing. And your tax dollars have produced it. It's terrific. But we don't know how to use it.

I mentioned these devices that control the transmission system and enhance capacity. They're expensive. The ideal way to use them would be to use this data from phasor measurement units through an automated control system to modify line characteristics. We've got the fax devices. We've got the phasor measurement units. We do not have any system to link them. So we think that's sort of a useful thing to do since the boxes are out there.

It's also the case that there are a lot of so-called smart grid technologies going in at the distribution level. Your tax dollars, or rather the deficits you will fund later on, have funded putting out a lot of very smart boxes in distribution systems. But what they do hasn't yet been published. So it's a little unclear. AARA is the stimulus legislation.

So we need more R&D, pretty cheap R&D. We need computational tools to use all this data. It should have impressed you with how closely coupled that whole Eastern Interconnect is. That from Florida to Minnesota, very quickly a disturbance propagates.

That means, if you think about it, particularly if you think about renewables, which I'll come to in a second, you need to be able to plan at the level of-- at that level, at the level of the Eastern system. The Western system is simpler. Texas is simpler. The Eastern system is the big one. We can't begin to plan that. The dimensionality is too high for current techniques.

And just to get to things I will come to in a little while, there's a lot of focus on preventing cyber attacks. There's very little effort on what do you do when you get one, one succeeds. But one will succeed. And we need to understand more about automated-- about dynamic pricing. I'll come to it.

This is a troublesome thing. There are technologies that have been standard in Scandinavia for 20 years, that are required in India, that can't be sold in this country because no utility has ever seen it work. The level of risk aversion is kind of breathtaking.

And it's like, why don't we measure things? Because if we put it in, and it's new, and it doesn't work, the utility gets hammered. The utility management gets hammered. The stockholders get punished. And the regulator gets punished. If you put it in and it works, everybody yawns.

So the regulatory system here in particular is biased against innovation in a way that's hard to fix because it's political. It's not technical. It's political.

OK, what about renewables? Well, there's going to be more wind and solar. This is renewable generation in the US, up to 2007. You see the big story is-- the big growth story is wind. Wood is very important. A lot of that is waste from lumber mills, that they just use it to generate power. Some of them sell to the grid, some of them don't.

Maine, a few years ago, passed a requirement for renewable generation. Did the numbers. Realized they had already met the requirement because of all the lumber mills.

You'll see solar here. Solar is in the data. But it's too small to see in the picture.

Since 2007, you see this peaks at about-- what do you figure-- 100,000. It's 173,000 in 2010. Over half of that was wind. So you see the wind-- wind has continued to drive the growth through 2010.

So that's renewables in the US. There are a lot of policies. That's Europe. This is putting aside hydro.

We were way ahead of Europe around 1990. We've stayed pretty constant as a percentage of total generation. Europe has shot up. And the European goal-- the EU goal is-- well, 20% of all energy from renewables. So 35% of electricity from renewables by 2020-- very, very ambitious.

There is-- well, you see Maine. This is 2007, non-hydro renewable generation as a percentage of the state total. Maine leads because of all the wood. California, pretty high; mostly geothermal, but wind and solar coming. And Texas, just an absolute generation, with a lot of wind, a lot of wind.

This is a policy map. It shows you the 29 states and the District of Columbia have renewable portfolio standards. Those are state laws that require-- generally, that require if you sell electricity at retail, x percent of that has to be renewable.

Usually much more detail-- you know. New Jersey has a requirement for off-shore, in-state wind. North Carolina has a requirement for electricity produced from-- I think it's poultry waste, maybe a separate one for swine waste. And they all vary. Rhode Island has three different levels of requirement.

So there's a lot of push for renewables. They're called renewable portfolio standards because the notion is, in your portfolio of generation so much of it has to be renewable. And we could talk about how these work. But-- well, they're all different. But you don't necessarily have to be physically connected to a renewable generator. But you have to make a purchase that amounts to encouraging that much generation.

I used to be able to say that every state but Arkansas subsidized renewables. But Arkansas put in a subsidy in 2010. So every state subsidizes renewables now.

Now, here's issue one. Issue one is, here's where the wind is. There's a lot of good wind offshore, in the Great Lakes. But offshore is expensive. The good onshore wind tends to be in the middle of the country. People tend not to be in the middle of the country.

So if you're going to use that, you're going to have to build transmission. And that transmission is going to have to cross state lines. I mean, there's a lot of wind in North Dakota. There are not a lot of people in North Dakota despite the shale boom. If you're going to use that wind, you're probably going to have to go from North Dakota, oh, at least to Minneapolis, and maybe down to Chicago, which is a problem.

Even in New England-- this is an impossible map. But it shows you where the wind is in New England, up here. That's offshore. This is where the load is in Massachusetts, and Rhode Island, and Connecticut. To get wind from Northern Maine, down here, you've got across state lines.

The problem is, states approve power lines. And states can block power lines. So my favorite is there was a proposal from Southern California Edison to build a line into Arizona, to connect to some cheap generation, and take the power to Los Angeles. And the Arizona Commission vetoed it. And one commissioner said, that's a 230,000-- a 230-mile straw sucking energy out of Arizona. We won't do it.

OK, each state can block it if it crosses federally owned land, which is I think a third of the land in the country. The federal agency can block it. Nobody can say, yes. We can build gas pipelines because those are federally-- federally done. The FERC approves gas pipelines. There is no such approval for power lines.

Well, if you're going to do renewables, there has to be. So one of our recommendations is to change that law. This is not necessarily popular at the state level. Because as I said, there's a lot of holding of power by the states. But if you want to build renew-- you want to use renewables that come from remote areas, you need to have somebody who can say yes.

OK so far? Questions on any of this? OK, that's one issue with renewables. The other issue with renewables is the fact that you can't dispatch them. You can't control them.

This is-- that's the output from a photovoltaic plant, solar cells, on a partly cloudy day. The output can change very rapidly, in a matter of seconds. There is no inertia in the system, no inertia in the system.

Now, if you a bunch of them, spread out geographically, this problem is reduced, but not eliminated because sometimes a whole state will be cloudy. So that's a real issue. And the no inertia means-- you think about the way power systems currently operate, there's a lot of rotating metal in generators, and turbines, and such, but particularly in generators. So if all of a sudden, 5,000 people turn on the lights, that's a big increase in load. But the system has what you call ride through capability.

You know, you've got all this inertia going through-- going in the generators. It just carries you through bumps. Well, there's no inertia here. There's nothing carrying you through bumps. And there's no real inertia in wind turbines. Not a serious problem at all, yet. But as you look down the road to a lot of it, potentially it is.

Wind-- this is total output of wind in California. The top line and the bottom line are individual facilities. And the access-- these are-- well, this is a whole day, right. So it's 10 seconds-- 10-second second sampling.

These are hours. And this is sort of characteristic of wind. Wind-- wind ramps, not minutes or seconds really, except for maybe some individual windmill that gets a gust. But over any reasonable area, it can ramp in the course of hours, from nothing to a lot, or from a lot to nothing. Both of those are problems.

This is the most discouraging graph I've seen on wind. This is a week in July 2006, when it was very hot in California. And the green is wind generation. So you'll notice that-- it has wind capacity of 2,600 megawatts. That week wind never produced more than a thousand.

And it varies over the course of the day, substantially. But here's the kicker. The red dots are the times of the system peak. The red dots are when the system really needed power-- late afternoon, in a very hot week. When it's really hot, the wind tends not to blow that much.

So not only is there a lot of variation that the system has to respond to, but at least in this case, the peak out-- the output at peak was tiny relative to capacity. So wind farms tend to have capacity factors, 20s and 30s. That is to say, about 20% to 30% of nominal capacity.

If you ran at 2,600 megawatts, 24 hours a day, you'd get x. What you actually get over x is the capacity factor. And it tends-- they tend to be 20%, 30%. Solar, not so much at night.

So that's the other problem with renewables, that you can't dispatch them. They're variable, variable energy resources, as the phrase goes.

This is another terrific picture. This is Bonneville. This is the Pacific Northwest. And this is over the course of 2009, early December 2009.

Saturday night, wind the output goes from nothing, so around 2,000 megawatts. Holds during the day Sunday, Sunday is not a high demand day, and then just as you're coming into Monday, ramps down to 0 by Monday night.

Now we're told that Bonneville handled that. Bonneville handled that by backing off everything they could possibly back off, and then bringing everything they could possibly bring up back online. Not easy. Double it, and the system wouldn't have been able to handle it, probably.

So wind output, solar output, are more variable than demand. And you can't predict them as well. There's a lot of work on predicting these things. There has not been a lot of research on forecasting wind at 50-meter heights; has not been a subject of much interest in meteorology until recently. It's very interesting now. Hard to get data, not a lot of weather stations at 50 meters.

There are a lot of other changes and thinking about how you reconfigure the system. The interesting thing from the point of view of the market design is you don't just need capacity in a power system. What you need now is capacity that can ramp, can go up fast, down fast.

The current market design doesn't provide incentives for building that kind of capacity or for making it available. So again, as we go forward, it's going to be important to figure out how to do this. How do we make the system more flexible so it can respond to wind and solar at higher levels of penetration?

Now, one answer that everybody has is storage. And here's from a recent report on storage technologies. There are lots of storage technologies, lots of them. The ones in widespread use are pump storage. And pump storage is terrific at this, perfect.

There's a round trip loss. You pump water uphill. You run it down through a turbine. It's great. You can start it fast, not seconds, but pretty fast. You can stop it pretty fast, not instantly. You got a lot of rotating metal. But you can stop it pretty fast. But you can't build it.

There's one in New England. Nobody imagines we'll ever be able to build another one. It's the problem of building dams. You can't build dams.

So this is a technology that's in some use, you could build more of. But this is compressed air, mostly in a cavern of one kind or another. Put a lot of air in under pressure, drive a turbine when it comes out. You can do that. There are about three of them I think in the world.

And then there are all these batteries-- and supercapacitors, which are kind of cute-- and flywheels. And they work. These are known technologies. We can build these.

These are sort of neat. These are batteries that are-- that basically work off either liquid cathodes or anodes. And things flow. And it's great stuff. And but they're all really expensive at scale.

This, you can sort of afford if you can build it. This is OK where you have a suitable site. Not great, but it's OK. And all this other stuff is expensive.

So it's very hard. This is the Holy Grail in electric power research. If you could do cheap grid level storage, solar and wind would not be a problem. But with technologies we now know, you can't. This stuff just does not look to have the prospect of becoming cheap enough to deploy at scale by 2030.

Could you do it? Sure. Could you afford it, probably not.

OK, questions so far. It's kind of a downer. But there we are. I mean, it is what it is.

And-- now the third thing. They're remote. They're intermittent. And they're expensive. So what do you do? You can do R&D. We've done some. You could do more easily.

There is an interesting question of, should you bring renewables on by subsidizing them or should you bring renewables on by taxing what you don't like, which is possibly coal, or carbon, or oil, or some mixture? There are carbon taxes in various places in the world, not that many.

What the US has done-- at the state level, we've had these requirements. What the Europeans have done is to basically pay prices. So if you put up a solar farm in Germany, your revenue per kilowatt hour is guaranteed for 20 years. In the US, you've got to find a utility that wants to deal with you, for the fact that you're renewable.

One argument is, why do we do it that way in the US? There are lots of problems with it. Because the cost is hidden. It hides the cost, I think is the main reason. It hides the cost.

In Germany, I mean you know there's a price. It's posted. In Spain, there's a price. It's posted.

In the US, how much does solar and wind add to our electric bills? We don't have a clue. Because there's-- there are deals done. But they're not typically public.

So we don't know. The fact that-- you may or may not have followed that onshore wind was-- that the Cape Wind-- you all remember Cape Wind, this project to build a bunch of windmills off Cape Cod, hugely controversial, also expensive? People were shocked that the price to be paid for that electricity was three times the going wholesale rate. Shocked.

Well, you're building windmills offshore, in the ocean, with transmission. And gas is really cheap. People were shocked because-- there were a number of interviews. People said, well, the wind is free. OK, the wind is free.

So we do this-- the other thing we do is tax breaks. And tax breaks give you this pattern. This is wind additions in megawatts over time. And you might ask, why it looks like that?

Whenever you see weird business conduct, the first thing you might want to look at is tax policy. These are the years in which either the tax subsidy was absent or in which it wasn't clear it was going to be renewed. And when that happens, people stop. And, of course, if you want to build a wind industry, that's insane because it means you can't ever gear up for production because next year you might not have any orders.

It's also a little problem with using-- we use tax breaks, too, because that hides the cost. You can cut revenue and subsidize renewable power-- or cut taxes and subsidize renewable power in one fell swoop. That's just fabulous. But, of course, if the firm doesn't have any profits, it can't use a profits tax break. And a lot of money is wasted making that work.

We also don't enforce much. So we have probably the worst possible policy mix. And the only explanation I've ever heard is that it's perfectly designed to hide the costs. The tax breaks-- who knows how much we spend. I mean, you can-- it can be found out, but not easily.

How much does it add to the cost of power? Well, it doesn't. It adds to your income taxes. What about these renewable standards, what do they add to the cost of power? Well, hard to know; bunches of deals, bunches of contracts, not ever really reported. So we hide the cost pretty well.

A carbon tax would be a much better approach. I should tell you, this is actually-- I find this fascinating. But the latest word from Washington is that the carbon tax is coming back. Remember cap and trade, the climate bill that we were going to have because both candidates in the last presidential election supported having a cap and trade program, which went down to defeat as cap and tax? Well, there now is serious-- serious work going on in Washington, as far as I can tell, on both sides of the aisle, preparing carbon tax bills.

They don't mention climate. Turns out, it's OK to tax carbon if you don't mention climate. You mention revenue, energy self-sufficiency. So we're going to have a carbon tax-- we may have a carbon tax to raise revenue without the word "climate" being uttered in the debate. It's fabulous stuff. Anyway, that's renewables.

Questions, comments, reactions? You're not terminally depressed by all that? OK. All right, I'll depress you some more.

Let's talk about prices. Prices don't reflect the nature of actual costs. Demand varies over time. You saw last time a supply curve. That says prices vary over time.

These are average-- these are daily average prices over 2010, in the PJM market area. That began is Pennsylvania, Jersey, Maryland. It's now broader. It's the biggest electricity market in the country.

And you notice a bunch of things. You notice they vary. You can sort of see a seasonal pattern. They tend to be a little higher in the summer on average than they are other times of the year. Not that much higher, because other times of the year you do your maintenance. So the supply curve shifts when you take units off to maintain them.

This must have been a particularly hot day. Who knows what happened here in December? A unit went off.

So the point here is you'd have kind of a hard time. You could predict this maybe that, yeah, it tends to be lower in the spring, and maybe what the hell is that? But you'd predict basically a summer peak in prices. But you'd miss a lot. You'd miss a lot of the variation.

You're talking down from $20 a megawatt hour up to $120. And this is not-- if we deaveraged and didn't do daily averages, you'd get more of a spread than that. You can get several orders of magnitude spread in marginal cost of electricity. You do not see that at home.

If you looked at the daily level, it's even more striking. This is a couple of days in 2010 by hour. And you see on whatever-- whichever of the two days this is, you had your morning peak and you had your afternoon peak. OK, you could kind of predict that.

I have no idea what happened on this day. This is like 1:00 or 2:00 in the afternoon, the prices shoot up. And that's real. That's the cost of generating electricity at the margin. That's a marginal cost. And it's at $300 a megawatt hour, they've put up pulled all the old dirty diesels out and turned them on for an hour or two.

So you can't forecast that. You don't pay that. Small commercial and residential users don't see that variation in cost. Oranges get more expensive at wholesale, they're more expensive at retail. Power gets more expensive, at wholesale nothing happens.

Now, it could happen. I mentioned earlier, advanced meters. What advanced meters do is advanced meters basically record usage at shorter short intervals, say 15 minutes; can receive price signals; can send 15-minute or even finer usage information to the utility.

So you could use these. And there are millions of them around the country. You could use them to charge those prices.

You can imagine exactly how popular that would be. You come home one day. And, oh, by the way you've just spent a jillion dollars for electricity because something happened.

So these meters, they're required in California. They're required in several other states-- everywhere. Federal tax dollars-- your federal tax dollars-- have paid for millions of them. But they're not being used. They're very smart meters, that are going to go slowly insane not using any of that intelligence.

They're not being used for pricing. They're not being used for measuring every 15 seconds because-- or 15 minutes because who cares? The price is the same.

So the one thing everybody is convinced of is if you just cut people over to pricing like that, there would be riots in the street because people would have nasty surprises. And people don't like nasty surprises.

You go away for a week. It's a heat wave. You forgot to turn off your air conditioner-- turn down your air conditioner. Boom, $3,000 electricity bill. You don't like that too much.

So it seems clear to most of us that the only way this works is if you can have simple automated response, simple automated response. The main issue is going to be air conditioning and heating. But even so, you might like some signal that says don't do your clothes at 5:00 in the afternoon. Something that says to you, electricity is really expensive right now. And for some things, it's got to be automated.

The flip side of all this price variation is a change in low duration curves. You recall, these curves you get by stacking the power-- by measuring power consumption each hour, and then graphing first the hour with the highest use, then second highest, and so on, down to the lowest.

These are low duration curves for New York, rescaled so that the peak is equal to 1, and averaged over 1980, '84, and 2005 to 2009. You notice they change-- it changes shape. It changes shape kind of dramatically.

In '80 to '84, with this 21% is, if you adjust size the system to meet peak demand exactly, 21% of your capacity would be used fewer than a thousand of the 8,760 hours in the year. That's a lot of idle capital.

But it gets worse, 2005 to 2009, that curve is peak year-- technical term. It has a sharper peak. And over a third of your capacity was used only a thousand hours-- less than a thousand hours a year.

So why? Well, the data are what the data are. There's two explanations that people have. The first is air conditioning. Because more central air conditioning in particular means more load on hot summer days. And hot summer days of the system peaks. So more air conditioning-- every unit in the state is on these peak times. And there are more units in the state.

The other is that-- it's interesting. If you look at the numbers in the '50s, industrial load was about half of electricity usage, about half. And that tends not to be seasonal. And it also tends to run at night a lot. It's now down to about 28% nationally.

So if it's all industrial load that runs 24 hours a day, this thing is flat. But as you get less of that, this back end falls off and the top end goes comparatively higher.

Now, everybody's got an air conditioner. But what happens when you have an appreciable number of electric vehicles and everybody comes home from work and plugs them in? So a plug-in electric charge that's sort of high capacity is a house. I mean, it's comparable in terms of load.

So electric vehicles, in areas where they penetrate, have the ability to make this problem a lot worse. And the reason it's a problem is you've got to pay for all that capacity. That's capital sitting there that has to get paid for. So rates go up.

So electric vehicles could have a disproportionate impact, if they spread, on rates. I personally don't think they're going to spread that much-- they're going to have great penetration by 2030. I'd love to be wrong. But in some areas-- Southern California, they expect-- probably Cambridge. I mean, who knows. But-- well, except for batteries and cold weather.

But Southern California Edison monitors automobile purchases in Beverly Hills, and Brentwood, and various other rich areas in Southern California. In Palo Alto, I'm told you can see parades of Teslas every so often. So there are some areas that will have a lot of electric vehicles.

And the obvious thing to do is if you take it to work, you plug it in when you come home. And that's exactly when the system peaks. That's exactly when the system peaks. So it could make this worse.

So if you can move loads off-peak, move charging to the middle of the night, have people dry their clothes at night-- run the air conditioner, as I'm told Walmart does, really hard at 5:00 and 6:00 in the morning, and then back it off during the day; and run it hard at noon, and back it off in the afternoon, you could flatten the curve.

But-- and there are programs in which demand responds to peak conditions. There are something like 2 million air conditioners in Florida that are centrally controlled. And the utilities are allowed to basically turn them-- well, turn them up in terms of temperature in system emergencies or system stress periods, not every day.

But in principle, pricing can take care of this. If you can make this electricity really expensive in those hours, you bring that peak down, use capacity more effectively, deal with electric vehicles. I mean, some people have said, well, you really shouldn't allow people to charge their electric vehicles at 5:00 in the afternoon. That is not politically possible.

Can you imagine being told you can't refuel your vehicle, and go out in the evening? No, that's not going to happen. If you can't make it a rule, then maybe you have to make it expensive. Well, how do you make it expensive?

Well, you use price. The technology is out there. You just have to do it.

So we think this is actually important. We also think this is going to happen. But there has to be some way to make it easy for households. The Department of Energy, some few years ago, put out a brochure in which you talked about new technology will let every household be an active participant in the electricity market.

Electricity is about 2% of the average household budget. Milk is probably more important. The notion that people actually want to sit around and look at electricity prices all day, that's nutty.

But you got to-- if you want to have them respond, they have to be able to automate the response. And that technology is just-- a lot of people playing in it. But it's not-- it's not there yet. People like Cisco drool at this, as you can imagine.

Cisco has hired people from electric utilities. Cisco is talking to appliance makers. Cisco sees this as a future. But we're not there yet.

As I say, there are a lot of these meters out. Your tax dollars have paid for millions of meters that are going slowly insane, not using their intelligence. So we actually think that it's pretty important to begin running sensible experiments and sharing data, so that we can actually deal with this issue using the technology we have.

Questions here? OK. Let me talk about distributed generation. This is a pure economic issue. And if you think about it for a little while, it's a really easy economic issue, but it's politically impossible.

So there are subsidies for distributed generation, rooftop, solar. California talks about a million solar roofs. Everybody loves it; except, of course, the utilities.

And the utilities don't like it for two reasons. One reason is, the grid isn't designed to have power generated out on the edge, particularly the distribution system. The simplest example is this.

Suppose the utility needs to work on a power line connecting to your house. So what do they do now? They go to the substation that feeds your house and they turn off that circuit. OK, suppose every house in your neighborhood has a solar roof, generating power?

Well, without those roofs, you turn off the substation. The linemen can go work on the line. It's safe. The line's dead. If everybody's got a generator, you have to make sure they're all disconnected. And as a former dean of engineering said, let's say-- let's say, there are 200 of them on the line. What's the probability that all of them disconnect properly? Oh, that's zero, close to it.

So that's an issue that's troublesome. Not impossible. There are standards being developed. There are technologies being developed. That requires investment.

The policy problem is trickier. Shouldn't be, but it is. So it goes like this. I get an electric bill from Instar. The electric bill has two components, my kilowatt hour consumption times an energy charge, which is roughly what they pay for electricity on the market; and the kilowatt hours I consume times a capacity charge. What's that?

Well, that's the way they recover the fixed cost of the wires. So if I put a solar roof on, I save the energy charge, which the utility also saves, and I save the capacity charge, which they don't save.

So on the one hand, there's an extra subsidy there. In addition to whatever other subsidies I get for putting a solar roof on, there's an extra subsidy. I get this illusory extra reduction in my electric bill. It doesn't correspond to anybody's cost reductions. The costs are still there. The wires are still there. But I get a cut.

OK, that gives me an extra incentive to install a solar roof. What about the utility? Well, it gives the utility every incentive to make it hard for me to install a solar roof. It's money out of their pocket. It's money they don't get to cover the fixed cost of the wires.

So I have a strong incentive-- a stronger incentive to put up a solar roof. And they have a strong incentive to resist my putting up a solar roof. This is not a great policy. if you care about solar roofs.

The fix is straightforward conceptually. That there ought to be a fixed charge, x dollars a month, that doesn't change with how much electricity I consume. And one way to convince yourself that makes sense is, suppose I install, not a solar roof, but I install a diesel generator in my basement. And the diesel generator-- which I vent the exhaust into my neighbor's yard, so that doesn't bother me-- so the diesel generator covers all of my electric needs when it runs. But I still connect to the grid for backup.

Now, if you're only charging me for the kilowatt hours I consume, I'm getting the backup for free. That doesn't make sense. So there ought to be a fixed charge. It could vary with your maximum consumption. It could vary with-- in Spain, you contract for a certain maximum. Your charge varies with that. If you ever exceed that maximum, it cuts you off; very clever system.

So I would contract for backup. I'd pay for it. If the generator went out, I pay a charge. I'd pay for the power. If the generator doesn't go out, I still pay for my share of the wires that I have to have connecting.

Now, I will tell you, we have made this presentation. I've made this presentation. Others have made this presentation. The state level, the federal level, utilities, users, everybody nods, and says, yeah, of course, but we can't do that. How can we do that?

The usual argument is, well, it would be unfair to poor people. Well, it would be unfair to poor people for everybody to pay the same charge. But why would everybody pay the same charge? Oh, but you then have to discriminate.

Well, shouldn't people who have used a lot of electricity, and have the capacity to use a lot of electricity, pay more than those who don't? Isn't that fair? Well, no, that's too hard. So this is a recommendation, that as far as we can tell has been floating around for 20 years and more, which may or may not get adopted anywhere.

So finally, let me do cybersecurity-- no clear authority. So here's a picture from NIST, that is sort of what the grid will look like the, road map for the smart grid interoperability standards. This is what they're working off-- or a cartoon of what they're working off in generating standards.

And every one of those lines is a communication line. There's computation in various places. There's communication along those lines. And some of them are thousands of pieces of equipment. Some of them, down here in households, are millions of pieces of equipment. They all have to interoperate. They all talk.

The standard setting problem is hard enough. But the fact is, they're all talking. That means there are all these channels that can be hacked, can have failures, can be sabotaged.

There was a great demonstration a couple of years ago, done for purposes of a video. A small turbine-- oh, yeah, it was a diesel. A small diesel generator was run. And they purposely hacked the control system and caused the generator to connect to the grid out of phase. The generator blew up.

Now, that's a hack that can take-- you take out a large piece of equipment, and that's not like days. That could be months to fix, or years. So it's a serious issue.

Most people are aware of it. But the response-- the governmental response is quite fragmented. At the federal level, there are standards. There are some compliance-- some regulation. Each state regulates cybersecurity in its state.

And I remember talking to one of the commissioners from Ohio. And he said, oh, we have workshops. We're getting all these guys to do standards. This is fabulous. I said, what about the municipal utilities and the co-ops in Ohio?

Oh, well, we invite them to come. There's no jurisdiction. They're connected to the grid. So no development or coordination of standards for distribution systems. Those are regulated by the states or not at all. And nobody deals with the whole grid.

So it's pretty simple. The simple recommendation, somebody ought to be in charge. There are people in charge of cyber-- the Department of Homeland Security has a chart that shows who's in charge of what. And it goes industry by industry, usually a match of agencies. Nobody's in charge in electricity.

The latest-- the latest statement from the administration is, the Department of Homeland Security and the Department of Energy will coordinate on this subject. Now, you don't have to spend too much time in organizations to realize that means nobody's in charge.

Everybody-- this is a recommendation that everybody agrees with. But there's violent disagreement over who gets it. The administration has said it ought to be the Department of Homeland Security. The relevant folks in Congress say it should be the Department of Energy. The current compromise that says let them play nicely together is something that no one thinks-- no one outside the Beltway thinks can possibly work.

So this is a look at the future of the grid. It's interesting. We did this study for two reasons. One, because we got very tired of hearing that we have a third-world grid. And it's all broken. And we're all going to die. That seemed a little extreme.

And then there's stuff about how smart grids are going to transform our lives, like the internet has transformed our lives. And we're all going to be active participants in the electricity market. And that sounded even dumber.

And we thought it might be worthwhile getting some economists and engineers to actually look at the grid. The conclusion we have is, yeah, I mean, you can-- there's a way forward. We're not in crisis.

There are real opportunities. They're not transformative. But they're real opportunities. But there are problems.

We need to do relatively inexpensive R&D, I mean, this is a software development, algorithm development. It's not nuclear power.

We need to be smarter about siting transmission lines. We need to move toward getting retail prices right. We need to deal with network costs appropriately. We need to deal with cybersecurity. If that all happens, you will live happily ever after. Questions? Yeah, Matthew?

AUDIENCE: Earlier in lecture, you talked about how the bill for the carbon tax mentions nothing about the environment. What would happen if it said, hey, this is good for the environment, too, as part of--

RICHARD SCHMALENSEE: I think the environmental-- well, it's not a bill yet. There's no point in introducing a bill into this Congress. There will be-- it is expected-- the expectation is that after the election, when there's some hope of people actually working together, a short window, that proposals for a carbon tax are going to come leaping out of the closet.

And those proposals will talk about revenue. And the environmentalists will be relatively quiet because if the environmentalists talk about climate, the Republicans, who have said there is no such thing as climate, will be backed into a corner, even though-- some of them have had to deny climate change to be in line with the leadership, even though they actually are capable of words of more than one syllable.

So some of those folks would be pushed to opposition. If you don't mention climate, they can quietly say, yeah, it's good for the climate and vote for it. I don't know if it's going to happen. It's a cocktail parity conversation. But it appears to be a fairly serious cocktail parity conversation.

Anything else? Yeah?

AUDIENCE: Are you going to be presenting tomorrow [INAUDIBLE]?

RICHARD SCHMALENSEE: I'll be presenting a longer version of this to a-- and a somewhat different version, but close to it-- a group of large electricity users. And I'm very interested in what they're going to have to say.

We've talked to state commissioners. We've talked to the federal regulators. We've talked to congressional staff. This is the first conversation I've had with consumers. So I'm looking forward to it, big industrials. Yeah?

AUDIENCE: Is the problem with cybersecurity that nobody wants to deal with it, or everybody wants to?

RICHARD SCHMALENSEE: Everybody wants to deal with it. Yeah.

The problem is that the Department of Homeland Security has no expertise in power systems. And the Department of Energy has no expertise in cybersecurity. So whoever gets it has to staff up. Well, staffing up is fun.

You add headcounts. You add people. You add payroll. You add prestige. So whoever does it gets to staff up.

If you split it, then you've got sort of dueling staffs. You don't understand anything about electricity. Oh, yeah. But you don't understand about security.

I mean, come on. That doesn't work. So everybody wants-- well, both people want it. And at some point, I assume, one of them will be declared the winner, but not soon. Anything else? OK, see you Wednesday.