[SQUEAKING]

[RUSTLING]

[CLICKING]

R. SCOTT KEMP: OK, so today we're going to start down the path of economics and trying to understand the justification for nuclear energy in the context of climate change. In a sense, I could put up this plot and then you can all go home for the rest of the class, because this basically embodies all the information you need to know by the end of the class.

OK, maybe I'm overstating it, but it'll draw you to the exact same conclusion. So this is a slide showing the levelized cost of energy. What is levelized cost? It's just one way of several ways to measure the cost of energy.

We'll get into what LCOE is. It's also called LCOE, Levelized Cost Of Energy. It's not the only way to do it, but it's a very useful metric.

And here it's plotted against, on the x-axis, various costs of capital and costs of equity. These are basically what the investor demands back when they make an investment in some kind of energy technology. And that has an effect on the total cost of electricity coming out.

So this is cost per unit megawatt hour. Megawatt times hours is power times time is the unit of energy. So this is per unit of energy.

And the key takeaway is to look at the ordering of these technologies. So here, we have the cheapest, solar PV, then onshore wind, then gas combined cycle. Will I tell you what combined cycle is in this class? Probably at some point.

Geothermal, wind offshore, coal, gas peaking-- which you can basically ignore. Peaker plants only come on during the middle of Super Bowl Sunday. They come on very little, so they're very expensive. But that's OK. And then US nuclear at the top.

So this is in the United States. And these orderings are different in other countries. That's an important thing to remember. In everything we do in this class, we're going to look at the US case, and then I will try to tell you a little bit about how other countries look.

One of the issues if you're in Japan, for example, solar is not so great because you don't have a lot of land area. And you tend to be at higher latitudes and it's not as effective, so solar bumps up and so on. But this is in the United States. And the key takeaway here is that nuclear is very expensive.

So why should we do nuclear if it's so expensive? Well, obviously you need some kind of motivation other than just the cost. And that motivation has traditionally come from a desire to deal with CO_2 emissions.

Now, one of the problems is that obviously a lot of these other things also, to some extent, deal with CO_2 emissions. And so we'll talk about that. But the central point I want to make here is just simply you don't do nuclear unless you have a climate change problem. That's basically the bottom line.

So we have a climate change problem. So let me just ask the class, how much CO_2 should we emit? Yes.

AUDIENCE: Zero, ideally.

R. SCOTT KEMP: Zero, ideally. Who agrees that ideally, zero is the right number? OK, what's going on? OK, so some people agree with this. Why do you agree? Why do you feel that way? Yeah.

AUDIENCE: If I'm saying ideal, as in waving my magic wand and I could just have that happen, I've been told many times that CO_2 is the main contributor to climate change and greenhouse gases. So if I could reduce the acceleration of climate change, then yeah, that would be great, if I was only waving a magic wand.

R. SCOTT KEMP: Well, I mean, what does it mean to wave the wand? Does it mean that you could just affect it? Or does it mean that it has zero cost to fix the problem?

AUDIENCE: Yeah, zero cost, wouldn't have any impacts elsewhere that I don't have to do the trade-off.

R. SCOTT KEMP: So that's not the case. So now do we still feel zero-- even though there's some cost, who feels that we should still do zero, even though there's some cost of abating carbon? Some people. Fewer people. All right.

Yeah. I mean, so that's kind of the right intuition. Here's a simple way to look at it. This is the fraction of CO_2 emissions avoided. Somewhere over here is 1. And this is the value of doing something with the next unit of something.

So here, we have the marginal benefit. So we remove one and we get some benefit in terms of climate. And it basically is maybe more or less linear. It may taper off down here at some point.

And then this is the cost of abatement. And in the beginning, it's relatively cheap to abate one unit. But as you do more and more-- in fact, if I had plotted this correctly, this line would start below the axis, because the cost to abate the first unit of carbon is actually negative, because this energy savings-- turns out changing your incandescent bulbs to LED bulbs on a life cycle basis turns out to save you money, despite the fact that the LED bulb costs $10 and the incandescent bulb cost $1.

But in the end, you save way more money on electricity and abate carbon emissions at the same time. So in the beginning, you're actually starting negative. And then it becomes positive.

But at some point, when you want to abate that last unit of carbon, you're going to have to put like some vacuum collector bags on the back of cattle to collect their farts or something. And do we have to walk around with masks to stop exhaling into the environment? Just as reductio ad absurdum.

But it gets obnoxiously expensive, if you want to go to zero. So the point is that there's some point where the marginal benefit intersects the marginal cost. And that is the optimal amount of carbon.

And if you start from the mindset that we should have zero carbon, you've already made a huge mistake. That's what I really want you to take away, because a lot of people read studies about full decarbonization of the grid, et cetera, et cetera. They want a zero-carbon society.

And they then make technology choices predicated on zero. And it's just at that point, you've already pushed us off a suboptimal position. And any analysis you do predicated on a zero-carbon world is the wrong analysis.

It may be very close to zero or it might not be that close to zero. We don't really know, but it is definitely not zero. And that's what I want everyone to bear in mind when you start looking at things that people are doing.

Tons of academics, myself included, have published papers on a fully carbon-free renewables grid and what that means. And that's an extreme case. That's not really where we want to wind up. Yeah.

AUDIENCE: So a lot of what I think people end up, I guess, wanting from this is a carbon production rate that's lower than the carbon reduction rate. As in the carbon rate's going down over time. So do we have a number for what the maximum carbon absorption of the Earth actually is?

R. SCOTT KEMP: Oh, yeah. I mean, so there is a lifetime of carbon in the environment-- a half life, if you will. I think it's over 1,000 years roughly. And that's what geoengineering is all about, somehow accelerating that.

Yeah, you basically can reach an equilibrium condition, if you have no more emissions, then it will go down. So yeah, there is a number in the very, very long time horizon that would tell you that.

But that a bit misses the point. That is engaging with something called the naturalistic fallacy, which is the idea that humans should not change anything. And it's problematic because it's just not how any species exist on the Earth. And it's problematic because if you look at the timescales involved, you'll see from historical data that CO_2 in fact fluctuates quite a lot.

And so it would be hard to defend that position in reality. This more near-term perspective is usually where you wind up. I don't have anything prepared on the naturalistic fallacy, but I can, if we want to talk about that more. It is an interesting thing. You can also look it up on your spare time.

All right. So the key point here is there's some amount, but it's not zero. We don't know what it is. So we want to set energy policy to get some amount of carbon reduction, TBD amount. How should we go about doing this?

And so who read Jasper? Yay, excellent. Some thoughts on the different models of how energy policy-- I mean, Jasper is particularly around nuclear-- but how energy policy has happened? Just throw out some words about some things that Jasper talks about. Yep.

AUDIENCE: He talks a lot about the idea of the social cost of carbon.

R. SCOTT KEMP: Oh, are you are you talking about Jasper or are you talking about Pindyck? You're talking about Pindyck. Yeah, Jasper was on last week's reading assignment. It was the one that talked about elites and discretion.

So Jasper talks about this idea that France had-- it was not driven by concerns around climate. It was actually driven around concerns around oil, because of the oil crisis. But they realized there was unacceptable dependency on foreign oil and they wanted to do something about it.

So they wanted energy independence. It wasn't clean energy. It was a different thing they were maximizing for. But they decided to go nuclear. And they went nuclear in a big way.

Whereas other countries-- and the paper talks about Sweden and talks about the United States. They instead said, well, let's look at the cost of nuclear. Let's look at the benefits of nuclear. And the decision was to wait and not do a lot of nuclear right away.

Now, in the United States, we did actually have a ramp up in nuclear around that time. It was actually the most nuclear that we've ever built. In Sweden, they built a lot less. But the article attributes that lower growth rate not particularly to a rational cost-benefit answer, but in fact to the politics of the social democrats who, absent consensus, just decide to do nothing. And so nothing was done.

But it talks about how there are different kind of philosophies of choosing which technology you want to pursue and how aggressively you pursue it. And so we can ask, what is the right way to do this?

Should we just choose a winner? Should we say nuclear is fantastic? Let's do nuclear. Or should we try to do this cost-benefit thing? But cost-benefit has historically not produced a lot of benefit for nuclear. Does anyone have a view on that? Yeah.

AUDIENCE: I mean, this is a lukewarm answer, I suppose, if you can get it. But it should probably be evaluated in a lot of different frames. But the economic has to be one of them.

R. SCOTT KEMP: Yeah. Yeah.

AUDIENCE: I think it's a political decision, at the end of the day. We have the Paris Agreement and the 2050, let's say, net zero targets. So I guess it would be very political. I mean, the decision will be influenced by--

R. SCOTT KEMP: Yeah, you're right. No matter what, it will be a political decision. And it's a political decision rather to do what the French did, which incidentally, is also-- I think I mentioned in the first lecture, the French and high speed rail also have this very successful early obsession in the '60s and '70s and '80s with high speed rail. But these are political decisions and people also can make political decisions to do cost-benefit.

AUDIENCE: Yeah. Politicians sometimes don't care about the economic benefit that much. It's different forces driving these decisions.

R. SCOTT KEMP: Yeah, that's right.

AUDIENCE: That's what I'm trying to say.

R. SCOTT KEMP: Yeah, yeah, yeah. So they may be, will I get votes if I don't support decarbonization? Will we look like we're a responsible country on the world stage if we go to the Paris negotiations and we don't come up with targets? Even though we know we're not going to make our targets, we're still going to put up targets. Yeah, this is all definitely true. Yeah, one more.

AUDIENCE: This may not be the time. I can ask after. But are there decisions that aren't political decisions?

R. SCOTT KEMP: Not really.

AUDIENCE: OK.

R. SCOTT KEMP: Yeah. Yeah.

AUDIENCE: I'm also thinking of, for example, switching to high speed rail, whether it's a decision that could be made long term, but it can also be thought of economically. But I know there's challenges with deciding the scale you're thinking about, like the time scale you're thinking about economically, and discount rates, which are debatable. So if switching to nuclear policy is great for a really extended amount of time, but that time is so long that the discount rate makes the benefits negligible.

R. SCOTT KEMP: That would be true, actually, for carbon abatement in general, nuclear notwithstanding. And so Pindyck talks about the problem of the discount rate. Basically, if it's above 2%, he says in his paper that it's almost not worth doing anything. And then the question is, what is the discount rate?

I actually was going to put together a whole slide on the construction of the Ramsey rate. And I didn't do that, but maybe I'll do that for the next class. Ramsey is the traditional approach to how you understand social discounting for dealing with these types of issues on an intergenerational basis. So I'll do that for a future slide. We can have a better discussion of that.

The basic point is that there really isn't a right approach. There are many problems with cost-benefit. We'll get into that in a second. But there are problems with command and control approaches.

There are problems with market approaches. There are all kinds of problems with all kinds of approaches. But I'm going to advocate for one approach, and that is a modified cost-benefit approach. And let me just talk a little bit about why.

So people who might know Doug DeMuro this is Concorde. Probably a couple of you got that joke. So this is a supersonic passenger aircraft that operated for 28 years. It flew from Texas and the East Coast of the United States to Paris and London. I think it went from New York to London in three hours instead of six hours.

The idea of flying people faster than the speed of sound was, of course, a fantasy held by aeronautical engineers for a long time. And it has a certain technical sweetness. Not that different from the technical sweetness of extracting enormous amounts of energy from little bits of rock.

But it has issues. So Concorde uses four times more jet fuel per passenger than a normal airplane. This plane releases the amount of CO_2 that a person like you would emit in a 30-year lifetime, in a single flight.

This is very inefficient in terms of petroleum, and all of this so that 100 people can save three hours on their trip to London. It's, of course, extremely expensive to operate. A round-trip ticket on this plane in today's dollars is about $10,000.

And the cabin was only 9 feet wide because it had to be for supersonic reasons, so it was very cramped. You set two by two instead of three by three. Really a benefit only for the super wealthy.

But it had a lot of externalities, consequences for others. So one of the problems was that it produced sonic booms. So you can imagine several times a day when this thing was flying, if you lived in its flight path, you were going about your business. And then you hear boom. And all the windows would shake, and so on.

And you can imagine if supersonic transport had become mainstream, we'd be hearing these all over the country. Every five minutes, it would just be extremely, extremely problematic. It imposes really heavy externalities, not just like to the quality of life and our ability to focus and do our homework, which is super important, but actually like rattling buildings to the point where they disintegrate faster.

All kinds of-- disturbing animal life in farming operations, so they're constantly stressed and then they have problems with farming and so on. So was this a good idea? I mean, it was technologically achievable. It is technically sweet. But it probably was not a good idea.

The cost to society far outweighed the benefit, I would argue. But you can see probably why it happened, because in a culture that is kind of obsessed with pursuing a technology without doing the cost-benefit analysis, these are the kinds of things that can happen. And so this is kind of the start to the argument for cost-benefit. Yeah.

AUDIENCE: I have to double check my dates on this, but wasn't that sonic booms over land almost immediately regulated by the FAA, because NASA had done tests on it in the '60s?

R. SCOTT KEMP: I remember there was a huge-- so there was a huge policy assessment going on to try to estimate the damage caused by sonic booms. I do not know if at some point during the course of events they decided to fly at subsonically over the little bits of land from New York. I'm not sure what they did from Texas.

AUDIENCE: I know as of now, it is illegal, and you need special permitting by the FAA. Because there's a couple of companies that are trying to bring supersonic jets back. See if they get anywhere.

R. SCOTT KEMP: Anyway, it's just kind of a poster child for what can go wrong if you advocate for technological enthusiasm as a way to deal with the energy problem. And the reason I raised that is because there's usually a number of students who, when they write their first essay, say, we just need to do nuclear.

And that's a technological enthusiast perspective, as opposed to a more quantitative cost-benefit solution. But cost-benefit is also problematic. One of the major problems is that it's really hard to know where to draw the boundary of your analysis when you're trying to do your cost-benefit.

So for example, in Massachusetts, if you own a car, it has been decided that you need to have your car inspected on an annual basis in order to drive it for safety reasons. They want to make sure that your brakes work and that your windshield wipers work and your headlights work. And that sounds like a great thing.

But when they made that policy, did they take into account every Massachusetts car owner having to take three or four hours off of work to go get their car inspected and the cost to the economy to do that versus the cost of the lives saved?

And so that kind of, oh, incidental cost might have not have been added when they did the cost-benefit analysis. So oh, the cost is just $35 to have someone inspect the vehicle. Well, actually, the cost is a lot higher than you expect it to be.

It's very easy to overlook things that you don't think about. And so these analyses can be incomplete. On top of that, not everything can be easily quantified. So a lot of times, we're worried about saving human lives.

And how much are you worth? How do we do that calculation? We'll actually talk about that in a later class. I think the government has decided you're worth somewhere between $2 million and $15 million, depending on what the problem is.

But it's pretty clear that different approaches produce wildly different values for human lives. And not all people value their lives equally. Some people are willing to drive cars. Some people are willing to drive above the speed limit. Some people go bungee jumping.

Other people who are incredibly conservative with things. So these are not simple questions. And then you have all these normative values that are also hard to quantify. Things like human rights, ethics, your emotional well-being.

These are things that you can attempt to impose on a cost-benefit model, maybe through boundary conditions. You can say, we will not accept solutions where the cost are imposed disproportionately on people on the low income communities. Like, we could have that as a policy overlay, but it is really tricky to figure out how to wrap that into a quantitative analysis.

Finally, you can't optimize for more than one thing. And if you have a cost-benefit equation, it's a fundamental axiom of mathematics, I guess. And this produces a problem, because you want simultaneously to minimize the carbon emissions of the system, but you also want to minimize the cost of the system.

You can't do both. You can minimize the cost subject to some allowed amount of emissions. That's probably the best you can do. But you can't also then go out and minimize the social inequality and minimize all these other things that you might also care about.

So yeah, I mean, I guess I can give you an example of that. These can be really difficult, these optimization issues. So we might ask the question like, how should I spend federal dollars on education?

Should we give every child on a budgetary basis the same amount of money? And some people will say, yes, that's the most fair way. Every child gets $10,000 a year of educational support through teachers and schools.

When you say, well, there are different communities that have different educational needs. We could say inner city schools in Washington, DC, which incidentally have truancy rates that would blow your mind, like 40% or higher. Yeah.

AUDIENCE: Define truancy.

R. SCOTT KEMP: Oh, people who don't show up to class.

AUDIENCE: Thank you.

R. SCOTT KEMP: Yeah. They really need a lot help, so we should give them more money. But then you have the problem that, OK, you can give them more money, but the marginal benefit of giving those schools more money is actually quite small. And the marginal damages to other schools, because their slope is steep, is actually quite high.

So you do a lot of damage to other students to try to reallocate resources to the students who need it more. So how do you make this optimization? And it's an incredibly difficult type of problem.

Anyway, so there are many problems. It's basically just as subjective as the technological enthusiasm approaches. Both of them are subjective. The difference between the cost-benefit approach and the technological enthusiasm approach is that with cost-benefit, you can at least have some semblance of quantification.

So it's not just you have some way of comparing apples and oranges a little bit. Now, how that is done is imperfect, but you can talk about that. You can at least put it in terms that people can discuss.

And two, every input is laid bare and is open for inspection. When you have elites making energy policy and just saying, well, we decide we want Concorde and we want nuclear reactors, then there isn't a debate.

And that is a problem, because then you are basically putting all the power into a small group of people who don't necessarily have all the facts at their fingertips and can't make the perfect decision. So if you believe in democracy as a way of-- or at least social discourse or dialectic as a way of moving forward, the cost-benefit approach gives you a framework for trying to do that.

So what is the measure of climate change? It's this factor called the social cost of carbon. This is what the Pindyck paper is about. It's an attempt to quantify numerically in terms of dollars the damages to society per unit of CO2 equivalent emitted.

So in principle, we would like to know this if we're going to do a cost-benefit approach. But if you did your reading, you'll see that Pindyck eviscerated the process by which this number is generated.

Which then leads us back to the problem. OK, wait, if this is basically not very useful, what do we do? So in case you didn't read Pindyck, let me talk a little bit more, just very briefly, about why this number is hard to obtain.

So it's a two-step process. First, you need to estimate how much CO2 produces what delta T in global mean surface temperature. And then two, you need to estimate how change in global mean surface temperature affects social welfare, which is usually measured as dollars of welfare lost.

So let's look at these a bit more carefully. The parameter of relevance after all the climate models do their thing is called the climate sensitivity. This is the expected change in degrees C temperature arising from a doubling of CO2.

And we began making these estimates in 1896. And as you can see, over the decades, there have been many estimates, including the emergence of the IPCC. This one, AR6, is the most recent IPCC assessment of climate sensitivity. The next one is due out in 2028.

And the basic takeaway is there's been no reduction in the uncertainty on this number in over 125 years of research. That is remarkable. And this is not a small range, 1.8 to 5.6. When people talk about the maximum allowed temperature change should be 2 degrees and your uncertainty is this big, what do you do?

So why is the uncertainty this big? Well, one of the problems is that it comes from feedback. The climate system has all these feedbacks. And it has this functional form. This is the Planck temperature change resulting from just straight up radiative forces without feedback from a doubling of CO2.

Then you have this feedback parameter, which is here in the-- it's a solution to an infinite series. And then you have the effective change in temperature. So let's just see what happens.

If your feedback parameter is negative-- so this feedback on the x-axis and this is the delta T over T0. So this is multiplier on the temperature. If the feedback is uncertain in this region, then the effect, of course, on the temperature is very, very tiny. It's really stable.

But if the feedback is-- what? There it goes. If the feedback is in this region, then the uncertainty is huge because of this shape of this curve. And in fact, this is the range of uncertainty that the IPCC currently specifies for this parameter.

They say somewhere between 0.5 and 0.7. And I will also speak to whether this is a credible number in a moment. But you can see here that this produces a large range in temperatures, which is why that uncertainty is really hard to pin down, because of the shape of this curve.

So you have a lot of people running around saying things like, if we don't constrain total atmospheric CO2 to 450 PPM, then all hell will break loose. And the answer is, well, maybe. Maybe it will be worse. Maybe it's too late. Maybe it won't be as bad. We don't know because this problem.

We're sitting here on the curve as it's shooting up. And we really don't have a good measure. Let's look at a little bit about what the IPCC says in terms of climate sensitivity. So there are lots and lots of ways to try to estimate this parameter.

This is what we call the instrumental period from last 40 years, where we actually have thermometers floating around in the ocean. And we look at volcanoes and various things that perturbate the atmosphere. And we try to understand the climate sensitivity.

And then you can look at ice cores and various other paleoclimate data. And one of the interesting things is that as you go to longer and longer time scales, the feedback factor appears to increase.

So it's not actually a fixed number. It's a number that is only true at one particular climate state. But the climate is constantly changing. And so the feedback parameter is constantly changing. So this presents a challenge in how you decide what this is. And it's worth pointing out that this is a wonderful opportunity for bias to creep into your calculation.

Because you can say, well, we should take into account all possible ways of measuring this and get a nice big f. And then you would say, and this shows that climate change is very imminent and dangerous. And because I care about climate change, I'm going to advocate for this approach and I'll call it conservative.

And then other people will say, no, if we just look at this particular line here, which is the most recent, then we see the climate sensitivity is very small, and so you're blowing things out of proportion.

So you can have these debates. IPCC has this debate. And it can lead to massive uncertainties in this number. So let's see what the IPCC says about its methods.

It says, confidence in the validity of a finding is based on the type, amount, quality, and consistency of evidence, theory, data models, and expert judgment. They also say that quantified measures of uncertainty in a finding are expressed probabilistically based on statistical analysis models or expert judgment.

And they go on. Estimates in this assessment are based on expert judgment. And then this is worth reading. In addition, examining expert judgment and decision making shows that people, including scientific experts, suffer from a range of heuristics and biases that affect their judgment.

For example, in the case of expert judgment, there's a tendency towards overconfidence both at the individual level and at the group level, as people converge on a view and draw confidence in its reliability from each other.

However, in an assessment of the state of scientific knowledge across a field such as climate change, characterized by complexity of processes and heterogeneity of data, some degree of expert judgment is inevitable.

So what is this saying? Well, it turns out that these numbers that I showed you here, these are done by just surveying people in the field and asking them, what do you think the climate sensitivity is? That's ultimately how these numbers are generated.

So if you are looking for that scientific, principled reason why you have to act now, and if you don't do xyz with respect to climate abatement, all hell's going to break loose-- it's not there. The statistics are highly uncertain or the measurements are highly uncertain. The effect is dominated by this weird, terrible function.

And in the end of the day, everything the IPCC says on this is just someone's opinion. So why? Well, Marcia Baker, who was the principal co-author of the IPCC in 2007 and a great climate scientist, said the efforts to reduce uncertainty in climate projections are impeded by fundamental gaps in our understanding of the climate system, or by some features of the system's underlying nature. And this is basically the issue, that getting a real number out of these climate models on which to act is really hard. Yes.

AUDIENCE: So a question about this. So if I understand correctly, the data on emissions are a little uncertain, or I guess very uncertain, like outrageous. Despite those uncertainties and ranges of when the consequences will happen, is it still possible to confidently say that all these greenhouse gas emissions and pollution that's being caused by a lot of technology, like fossil fuel technology, is inherently bad, even if we can't say exactly what?

R. SCOTT KEMP: Yes, absolutely. Yeah. So his question was, can we still say emissions are inherently bad, even though we can't quantify how much temperature changed? Yeah, I think that much of the science is clear.

Like, you put CO_2 into the atmosphere. It traps infrared energy from leaving the atmosphere. It drives radiative forcing that produces a warming planet. But it kind of quickly doesn't take you anywhere.

So for example, if you look at the amount of CO_2 that we've put into the atmosphere and you look at how much additional radiative forcing, which is about 0.7 watts per square meter on the surface of the Earth, that you would get from that CO_2, and you integrate that over the surface of the Earth, and you integrate that over the time that we've had that extra CO_2, you would get a value for energy-- total energy added to the system.

If you take that energy and partition it strictly into the mass of the atmosphere, we died a long time ago, because the current average temperature would be like-- I don't remember the exact number. But it would be close to boiling on the surface of the Earth, something like this. But that's not the case. So where did the energy go? Yeah

AUDIENCE: I think in this case, actually, I've read the ocean acts-- the water is a carbon sink, basically.

R. SCOTT KEMP: It's not that it's acting as a carbon sink. It's acting as a heat sink. So the ocean has 1,000 times the thermal capacity of the atmosphere. So it turns out 99 point something percent of the energy eventually is sunk into the ocean, which can absorb way more energy.

And here's the issue. We cannot constrain the heat flux across the ocean-atmospheric boundary to better than plus or minus 20 watts per square meter. Remember, the total radiative forcing from climate change is about 0.7 watts per square meter.

So it's totally in the noise of our ability to constrain where the heat in the place where we live, in the air, is coming from. Is it coming from the ocean? I mean, there's certainly energy being added by the top of the atmosphere, unquestionably.

But what is actually driving the temperature on the surface of the earth? It's the ocean that drives it. And until we actually understand that, we can't really make a statement about whether the energy being added by the CO_2 is unacceptably large or not.

That's the challenge. So the climate models attempt to model this by parameterizing a whole bunch of variables and making those models match historical data. But they tend to diverge wildly after the historical calibration region ends.

And then they take the average of them. And average of a model is not actually the-- the average of a bunch of ensemble of models is not a measure of uncertainty-- or the range of an ensemble of models is not actually a measure of uncertainty in the system.

So it turns out, once you start looking for a quantitative assessment, it gets really hard. And it basically boils down to, yes, CO_2 does warm the atmosphere. We don't know how much damage it's going to do.

People who work in this field are making a guess. And we as energy policymakers are asked to do something about this. And we are supposed to come up with an optimal solution. And if some people are laughing, that's the correct response. It's really hard to do this.

Pindyck talks more about this part of the calculation. So that was just to talk about the delta T. Then you take the delta T And you plug that here into something that gives you the loss to society. And he talks about these models being offered by various people.

And the models have been contrived so that they have this shape, so that if you go above a certain temperature, it's very dramatic here. According to this model, if you go above 1.9 degrees, then 100% of loss to society virtually.

These are crazy, crazy parameters. The fit, beta, and pi, they say, are just arbitrarily chosen. They say the models are arbitrarily chosen. What is this? This is a noise amplifier.

It takes a noisy kind of crummy measurement coming out of T and produces pure noise. So the social cost of carbon is basically not a number that we can really calculate. Yes.

AUDIENCE: What are the actual units for loss? This is one of the things that was--

R. SCOTT KEMP: They often do it in terms of a fraction of GDP.

AUDIENCE: OK.

R. SCOTT KEMP: Economists like to use GDP. All kinds of ways you could do it. But yeah. So in this case, it's fraction of GDP. So how do we move forward? Like there's no basis to do anything. What do we do? Yeah.

AUDIENCE: I mean, you can make non-CO2-- fuck, I cannot speak today. I'm sorry. Related arguments for other power sources, right? Nuclear's case--

R. SCOTT KEMP: You're putting the cart-- but don't put the cart before the horse. Don't like, oh, well, if I can't justify it with CO2, let me find something else to justify it with. The question is, we have a CO2 problem. What are you going to do about it?

AUDIENCE: Well, I was going to say the main issue is it's not if it will happen, but when exactly, right? If I'm following correctly.

R. SCOTT KEMP: That's also true. But it's not will it happen, it's to what extent will it happen, and so on. So there's a lot more to it. Yeah.

AUDIENCE: As in long-term solution-- I mean, I know one of the main criticisms is, oh, this takes too long. We need to act now. And that opens up the door to longer-term solutions, I think.

R. SCOTT KEMP: Maybe. I mean, you could argue that if we don't have to act now, then we could explore fusion. But if we have to act now, we better just use wind and solar.

AUDIENCE: Yeah. And more fission projects.

R. SCOTT KEMP: Yeah. Well, if you really care, fission takes 10 years to build. And the amount of wind and solar you can build in 10 years is insane. It's much, much bigger.

AUDIENCE: Do they have an end-of-life plan for the wind and solar?

R. SCOTT KEMP: I don't have an end-of-life plan for you. I don't know.

AUDIENCE: A lot of the photovoltaic cells last about 20, 25 years. And nuclear can--

R. SCOTT KEMP: All of this can be talked about. Let me get into some other questions. Yeah.

AUDIENCE: [INAUDIBLE] kind of sticking with the carbon issue, but also the slightly adjacent tangent. You could consider factors like other sources of renewable energy still have carbon emissions within the process.

Some of the fossil fuels are projected to run out pretty soon, especially if the data center AI issue kind of goes out of hand. So that regardless of when this will happen, it's still beneficial to invest for a very long-term approach into nuclear, especially like fission.

R. SCOTT KEMP: Yeah, so one of the challenges we're talking about investing in the development of technology is it's really hard to know what you'll get out of an investment. You need a crystal ball to see that.

And so you can make kind of like hand-wavy arguments in that direction, but you can't really build an energy policy on that. You kind of build an energy policy on like, this is what we need to do to provide energy to our people.

And then we also, as a matter of industrial policy, say we need to also innovate and explore a variety of new technologies. And if you ask me, how do we optimize the amount of dollars going into that, there's no good way to do that? That is, again, a very subjective thing.

OK, so let me give you my answer. Here's what here's what I suggest we do. We'll treat the economic benefit of energy as a cost-benefit analysis. But we'll treat the economic benefit of energy as basically being independent of the source, subject to a constraint that the energy is available.

So a kilowatt hour of electricity from nuclear is just as good as a kilowatt hour of electricity from solar if the solar is there when I need it. So I impose this constraint in the modeling.

And then I say, we're going to balance that against the cost-- what we call the internal cost or the explicit cost of the electricity production-- and the estimated externalities, which include pollution and noise and all kinds of things. Coal, PM10, the use of land for windmills, killing birds, all these things.

And then we will treat the social cost of carbon as a free parameter. And I will just let you decide what you believe is a real SCC number. But what we can do is we can move this around across a couple orders of magnitude even. Subject two.

AUDIENCE: Oh, thank you.

R. SCOTT KEMP: We can move the SCC around and basically explore the space. So that's what I propose to do in this class. So we won't pick a social cost of carbon. We're going to let it float. And we're going to explore what we can do with this.

So just to remind you of a couple of things, a model is only as good as the data that you put in it. So a lot of time is going to be spent on trying to make sure these numbers are right.

In fact, we're not even-- well, except for this, because we're going to assume these are all equal, basically. But we're going to spend a lot of time on this. And as it will turn out, for nuclear-- I'll talk to you in a minute-- this is actually going to be a really important factor. And two, I said this earlier, but all these cost inputs change depending on what country you're in. So we have to bear that in mind.

AUDIENCE: If we're going to be agnostic to the source, how is it possible to estimate the externalities when they're dependent on the kind of sources you have?

R. SCOTT KEMP: We will be agnostic to the source only with respect to the idea of benefit, not with respect to cost. Does that make sense?

AUDIENCE: But you would need to know what kind of source you have to know what kind of externalities are applied.

R. SCOTT KEMP: Yes, that's correct. But the externalities are all down here. And so we will take the source into account for this and for this and for this. We will use information about the source to talk about how much CO2 is emitted. We will use the information from the source to come up with a number for the externalities and for the cost of the source.

But then we won't bother to say that electricity from wind is better than electricity from nuclear for some reason. Like, we'll only look at that on the cost side. Do people have any issue with this approach? Yeah.

AUDIENCE: Don't we run into the same host of problems with estimating externalities?

R. SCOTT KEMP: So we will-- so yes, there would be lots of problems with externality estimation. And what I'm going to do is I'm going to kind of show you two ways of trying to bound it. One is I will look at the most intensive study of externalities ever done and tell you what they said.

And then we will look at a meta analysis that averages across all the externality studies done, and looks at the median values and see what that says. And as it turns out, the answers from both of those are very tiny compared to the variance in this. So it won't really matter.

The only place that externality matters is going to be here in the social cost of carbon. But we're treating that as a free parameter. So if people are on board with this, that's what the first whole half of the course is going to be trying to do this in a way that is fair.

All right. So I'm putting this slide back up, and why? I guess it's a preview. Solar PV, wind, geothermal, and nuclear are all basically zero-carbon technologies.

That means with respect to this, they all have the same penalty, which is like no penalty. And so now you can see why this parameter actually becomes dominant in the equation.

And so a lot of what we're going to talk about constantly is about the cost of electricity, the cost of nuclear, the cost of wind and solar, the learning rates that bring down the cost, the cost, the cost, the cost. And the reason I want to talk about that is because, in fact, that is the only parameter that really matters at the end of the day. So this is just a preview of why that is. But we'll get back to this.

All right. So let's see. We'll focus on the United States. I guess the other thing to mention is that the models are-- the numbers for these models are kind of frozen in time. They are numbers that exist for a certain level of technological development.

So what we'll do is we'll baseline our results to the technology that is available now, the costs that are available now to come up with answers. But we will attempt to look at-- we will have some discussion about learning potential to evaluate our ability to bring down these numbers and to see, OK, this may be the situation today, but if we build a lot of nuclear, how much can we bring the cost down and therefore affect this parameter? So we'll do one and then we'll look at the learning as a second factor. Yep.

AUDIENCE: When we're looking at this equation, is this under the assumption that you're trying to produce all of your energy within whatever country that you're looking at? Or is it also looking at purchasing from other countries? Is that lumped into the externalities?

R. SCOTT KEMP: We will only do it for the United States, which doesn't really purchase electricity from others. But a fair analysis is to basically do this for any country on the basis of what it does. So if they do buy a lot of electricity from others-- I guess you could say-- let me take that back.

I guess you could say we buy a lot of solar panels from China. And so the externalities associated with solar panel production in China are much higher than they are associated with solar panel production in the United States, because they pollute more. And they also use much more carbon-intensive electricity to fabricate the solar panels. So they incorporate more carbon costs in their life cycle assessment.

But it turns out that that still turns out to be a very small parameter. So yes, you should, in a sense, incorporate those other factors. But in the end we're kind of going to gloss them, ignore them, because it just turns out they're not that big of a deal. Yeah.

AUDIENCE: Yeah, my question is going to be if and how exactly we're going to deal with, I suppose, that whole aspect of generating energy and when it's available. Kind of tied to that, the value of energy, time value, as you see for high solar penetration, that the price or just the value at that time is low or even negative, if that's going to be accounted for. Because the LCOE obviously accounted for that.

And then tied to that as well, system costs for extra transmission, I suppose it could go in externalities or in cost itself. And then actually something I only thought of based on the previous question, but in terms of value to who, the GDP multipliers are very different for the different investments in different technologies.

Like you mentioned, we're buying solar panels for from China versus investing in workers, building a hydroelectric facility or a nuclear plant. So kind of like, I suppose the bigger question is, are we going to take into account value in this picture? Because if we say economic benefit is assumed to be equal, then that does not seem to really match up with reality.

R. SCOTT KEMP: OK, you raised a lot of super good points. So on the issue of how do we do the subject two part, the availability, we'll talk about that. You'll see if you go through the syllabus there's a whole section on the grid. There's a whole section.

And the reason is because that's all subject to the availability. We'll talk about that. So yeah, we will talk about using things like GenX to model greenfield estimation, so that we properly account for the variability in wind and solar and its time sensitivity, that it's not just that it's variable, but variable at certain times of day. And to your final point about GDP multipliers, we're just not going to talk about GDP multipliers.

I'm not sure how defensible that stuff is. It's, again, where do you draw the box? Like, you say, well, here's my expensive technology, but I've identified this effective way to have a GDP multiplier because it does this.

And I'm like, yeah, but if I don't have to spend all that money on energy and I just put it into the economy and it does other things and it invents GPUs instead, and then we get AI-- like, it's impossible to really do the GDP multiplier, I think, in a defensible way. So we're just not going to go there. Yep.

AUDIENCE: Will the estimated externalities be for normal operation or will it build in some kind of risk of accidents?

R. SCOTT KEMP: We'll start with normal. And we will then have a whole section on accidents. And we'll calculate the expectation value. It turns out the accidents is basically not a big deal for anything except for nuclear.

And we'll calculate the expected cost. And we will recalculate the deaths per terawatt hour plot that you see floating around on the internet, which has no defensible source. I really encourage you to go look at the sourcing for that and try to figure out where they get those numbers. You will do a calculation in this class that you can believe. That plot is crazy.

All right. So we have 30 minutes. We have agreed to some kind of economic assessment. And I am not going to teach you microeconomics in 30 minutes. But what I'm going to do is I'm going to just do a little bit of microecon philosophy for 30 minutes.

And then in the next class, we'll do a little bit of microeconomics, supply and demand and externality, because there's one more factor that comes into play that explains why these two parameters turn out to be not that sensitive, related to the elasticity of demand. Yes.

AUDIENCE: Just a clarification. Is the cost of nuclear waste disposal included in the analysis or will it be included in the analysis?

R. SCOTT KEMP: We'll talk about it as a policy issue. But basically, the cost is believed to be tiny. Yeah. So we'll have a class about the policy problem of dealing with waste and why waste is still a problem. Why haven't we dealt with it? In the United States, in particular, the history of Yucca Mountain and so on.

OK, so if we're all good with this economic approach, let's just do a little bit of econ refresher to get us thinking in quantitative terms so that we have a shared vocabulary and that we can think about these things in an equitable way.

All right, so let's talk about what is the value of water versus the value of diamonds? Incidentally, I just learned that diamonds are very prevalent in the solar system, just not prevalent on Earth.

They tend to be in all kinds of meteorites and stuff. They're all over the place. Yeah. So what is the value of water? Which one is worth more?

AUDIENCE: Depends who you are.

R. SCOTT KEMP: Depends who you are. Depends what you have.

AUDIENCE: What do you need?

R. SCOTT KEMP: Yeah, right? OK, here's the problem. The word value is just like, what is-- we need a better word than this. Yeah. So obviously you need water to live. It is arguably of infinite value to you. And yet you can get it at the drinking fountain or on the corner for free.

So is it zero or is it infinity? And diamonds are pretty useless unless you're trying to, in my opinion, grind something. Then I like diamonds. But otherwise I don't have any need for diamonds.

Yet they're exceedingly expensive. So actually, this was a question that went all the way back to the time of Aristotle. And for centuries, people did not have an answer to this seeming paradox.

It was only essentially at the end of the 19th century, starting around 1890, that economics formalized to the point where they could deal with this paradox. It's amazing it took them that long.

So the key thing is to understand that all valuations presume some kind of context. And the value in use and by whom is not the same thing as the value of the inputs needed to make the product. It's not the same thing as value in trade when you exchange it.

When you look at the price of something-- that is the price in trade-- which is not what it cost to make. And if you're complaining about this price not equaling that price-- it cost them nothing to make this. Pick your favorite overpriced shoe or New Balance shoe with nice colorway or whatever you're into.

Obviously, that's not true. And then the value in use is obviously very different than that. So we call this utility. We call this one cost. We call this one price.

So we need to be careful of that. Occasionally, we will use the word value when we're not talking about any of these things or it's obvious. But I mean, we should be careful to use good language on this.

It's also worth noting that calculating this, the value in use, someone's utility, is not something that you can really do in a commeasurable way. The utility of a good-- this was actually just said earlier.

The utility of a good to you depends on all the other goods and services that you A, have, and B, desire. So if I offer you a banana, that depends on whether you're hungry or not hungry.

It depends on whether you're going to the Banana Lounge next or not going to the Banana Lounge next. And so it doesn't exist in a vacuum. These things can't be computed for individual people. It's very high dimensional function.

It's also the case that-- I think, actually, I have a second slide for this. All right. So because of these trade-offs, we can imagine a trade-off between some quantity of item A and some quantity of item B.

You can think of this as like a slice, a topographical map slice in a high n-dimensional surface. And these are, if you will, indifference curves. So any solution on this curve gives you utility units 1. Any solution on this curve 2 and 3 and so on.

And A and B can be anything. Goods A and B can be cookies and milk, pens and paper. It doesn't really matter what it is. A key feature of these curves is that they are convex. They have this shape to them.

And that means as you take away a little bit of item A, you need a disproportionately greater amount of item B to offset. So if I'm a dunker and I like to have milk to dunk my Oreos in and you take away my milk, then I might need a whole packet of Oreos to compensate for the fact that I don't have milk to dunk my cookies. Yes.

AUDIENCE: Is this assuming items that have value intrinsically tied, or is it just any two items?

R. SCOTT KEMP: Everything is intrinsically tied at some level. It's like, what is the value of, let's say-- it's hard to come up with things that are not tied. What is the value of your backpack versus the value of your mattress?

Well, at some point, if I take away your mattress and you can't sleep, then you're not functioning. And going to school doesn't really matter anymore and the backpack becomes useless. They all become tied at some point in life, because you ultimately need all of these things to function, even if they're not obviously immediately tied like cookies and milk.

AUDIENCE: Yes. But for this graph--

R. SCOTT KEMP: You can put anything. They all tend to have this convexity. So because they are convex, then there is typically an optimal condition given any budget. So here, we have this is a line of constant budget to buy these things. Given some price P1 for item A and given some price P2 for item B, you take your budget divided by P2, and that shows you how much of item B you can buy.

And then you can buy anything along this line. That's what your budget allows you to buy. And you can see that there is a point that the budget touches the highest possible utility curve. And then that would be the optimal amount of A and B for you to by, given your budget, assuming everything else is held equal. And so in economics, that assumption is called ceteris paribus. It applies to basically everything we say in economics.

So because most people exist on a budget line, they have a certain amount of wealth associated with them to do stuff, they can often-- but if I give them some arbitrary number of A and B, they can often improve their situation, move up the utility frontier, if I allow them to trade. Then they can reoptimize the amount of A and B by trading with people who have too much-- trading my A for-- I have too much A. I can trade with someone who has too much B, and we can all improve our lot.

And that is the idea behind the market. And if we do that vigorously, we will reach a condition that economists call Pareto optimality. Do I have a little box for Pareto optimality? I might have a box. There it is.

So Pareto optimality is a condition in which no further improvements to society's well-being can be made through the reallocation of resources that makes at least one person better off without making someone else worse off.

So of course, I can move myself up this curve if I take away someone's cookies. But I have made them worse off. So that is the condition of Pareto optimality. And this will come back a little bit when we talk about the problem of externalities.

So this basic virtue of the market, here's a question. Does this market, this exchange of goods, need rules? Or do we just let it happen, laissez faire, right? Yeah.

AUDIENCE: What do you mean by rules in this case?

R. SCOTT KEMP: Should I say that you have to-- I don't know. You can't have anticompetitive practices. Everyone has to get the same price. You can't stifle competition. You have to-- these are kinds of rules that you can impose on a market.

AUDIENCE: Wouldn't it depend on your belief on human behavior and what you value?

R. SCOTT KEMP: It depends on a lot of things. Yeah. Yeah. So this is a huge debate. So right now, there are 10-- typically, there are people who are free market people who are like, we don't need rules. The market will find the optimality.

And other people are like, oh, no, we need rules. We need to have regulations on pollution. We need to have rules about equitable allocation of resources. We need to have all kinds of rules to prevent problems.

An example du jour might be algorithmic pricing. Has anyone heard of algorithmic pricing? Yes, everyone has heard. So algorithmic pricing is something that hasn't existed traditionally because people were typically price takers.

You put the price out and you would buy and you would adjust your price, but everyone gets the same price. But now people are like, oh, I can actually charge you a different price than I charge that other person.

And so now this is a way to extract more from people. Does that have an effect on total social welfare or does it have an effect on equity? Yeah. So this is an important question and we will talk about it probably not in this class, but in the next class.

So these two curves can be anything, as I said. And they can be energy. And they can be CO2 emissions avoided. So now we're trying to concretize this into the climate change debate.

So maybe most people's indifference curves look somewhat like this. And if you're a person that has this budget, you can find yourself on this indifference curve and you say, OK, this is the amount of energy I want to consume, and this is the amount of CO2 avoidance I'm willing to pay.

And that basically is kind of the micro level equivalent of this plot. It's finding the optimal, but for yourself. It's not for society.

But if we let them happen in the market, then theoretically, the market does this for society, translates into this plot. Where am I?

OK, but what if I'm a very poor person? So maybe my budget curve is a lot smaller. So now, here I am. I'm like, I need some energy. And there's really no utility curve that gives me value to the emissions reduction. I could buy it, but it doesn't give me utility.

So you could argue that carbon abatement is, in a way, a luxury for the rich. Poor countries that are struggling to develop, get ahead, will tend to build polluting coal plants because they're cheap and they don't really care too much about climate change.

For them, this is a luxury problem. The temperature goes up a few degrees while they're trying to lift millions of people out of poverty, so be it. So you, being young and educated about the issues of climate change, might ask, well, isn't this just a problem of information?

Don't they just not-- if they understood that climate change is going to lead to these catastrophic consequences for the planet, wouldn't they too care? And the answer is no. Yeah.

AUDIENCE: Well, just going to say, isn't the common, not unreasonable, thought of well, you got rich because you used all this carbon. Now you're saying I have to follow your rules that you're making and living with your problems?

R. SCOTT KEMP: Yeah. Yeah.

AUDIENCE: Just to add on this, the Western civilization extracted a lot of value from, let's say, the third world, African countries, et cetera. So it's not fair for them, actually, to comply with the new rules imposed by the West. And they are behind.

R. SCOTT KEMP: Absolutely.

AUDIENCE: I was going to say recently I saw a discussion about someone-- don't remember what the bodies were. I just saw this in passing, about gas stoves or coal stoves, that someone was like oh, we should ban these in developing countries because it's not good.

And they're like, but people want to cook their food. I'll have to find that information. That was a recent discussion of like, you can't just tell people no.

R. SCOTT KEMP: You can't tell people no. And the thing is, it applies not only to people in Namibia. It also applies to people in rural Arkansas. And that's kind of the problem with trying to make national policy, is that people have different curves.

And even though you may care a lot about climate change, and you're willing to spend a lot of money on it and choose expensive technologies, other people are not. And if you impose, via technological enthusiasm or command and control economy your preferences over their preferences, you are forcing them to live in a suboptimal condition.

So given the diversity, how do we make a policy approach that is fair to everyone? And there is no obviously correct answer. Many decades ago, welfare economists talked about the idea of trying to maximize utility across the whole population.

But it's obviously not possible to even measure. I mean, I don't even know what my own utility function is, never mind finding some way to measure everyone else's utility functions. Hard enough for me to decide what to eat next.

So this is basically why the communist command and control economies of Russia and China really have not succeeded, because they really can't make these optimizations across a huge number of individuals who have wildly difficult and difficult-to-perceive utility functions.

So the idea that most modern economists advocate for is that the market-based economy, where you have individual actors making choices for themselves, choosing their own-- whether they want green power or they want polluting power, and giving them the choice, is a way that leads to a Pareto optimal outcome for all of society.

That is the argument. And then the reason for money is that if I'm a person who makes donuts, but I have to trade my donuts for things, it's tricky. But if I can engage in the market with money, then I have this nice, fungible unit that allows me to go in and do this optimization easily.

And if we do this vigorously and there are no distortions in the market and all the externalities are somehow internalized in the price, caveat, caveat, then we should be able to reach the optimal social outcome.

So that is at least the theory. Let's see. So I had a little example. I don't remember. All right. So a moment ago, I mentioned money as being this vehicle by which we're engaging in the market.

And I want to point out that we ought to be very careful with how we think about money. It is a way to engage in the market, but it is not a measure of utility.

In these curves, we're talking about optimizing your utility. But that is not measured by money. So rule number one was that there are all these different types of valuations and that utility can't be measured.

Rule number two is kind of an extension. It's that money is not a universal measure of utility between people. So $10,000 to you does not mean the same thing as $10,000 to Elon Musk. And that presents us with a problem, because we could say, OK, what if I want to pollute?

Can I to compensate the people on whom I dumped my pollution by paying them to offset their damages? And the answer is not easily, because the amount of money you'd have to pay a person is different for every person.

And indeed, you have to pay Elon Musk a whole lot of money if you happen to pollute Elon Musk's backyard. So this creates a problem with trying to compensate for externalities outside of the market system. It's really not easy to do.

It also points out that essentially, markets don't guarantee equality at all. All they're doing is finding a Pareto optimal solution. But they don't guarantee-- which means you can't improve the lot of an individual without harming the lot of someone else.

But it doesn't say that everyone has to have the same utility. It does nothing to deal with that part of the problem. So even though we prefer the market solution because we can't do the utility optimization task, we should just understand that the markets are not buying us the ideal world that we would really like.

Ways we typically deal with this, we talk about equity or now more recently the term justice. And we apply these policy overlays where people can decide that in our society, we prefer xyz to occur.

Like, we prefer not to dump pollution onto poorer communities. Therefore, we will have an overlay. But it's not something that the market is going to do automatically. The market will just maximize wealth generation, in a sense.

All right. Problem number three, not everything is traded in the market. So this we've actually talked about a lot. These are externalities. Pollution is the classic example of this.

Not only is it hard to capture these things in the market, there are features about these externalities that can sometimes be really problematic. So when we're talking about CO_2, of course, one problem is that we can't calculate the social cost of carbon or the damages from carbon are not internalized.

But the other problem is that climate is a non-excludable good. And that means that if I damage the climate because I don't care, but you care, my choices spill over onto you, and it makes it difficult for you to optimize your choices.

Likewise, if I decide I care about the climate, so I'm willing to spend a lot of money, then someone who's maybe also cares about the climate, but is a little cheap, gets the free ride, and they get to benefit.

In fact, if everyone is being strategic about it, they would all wait for someone else to pay for it. And so this is called the free rider problem.

So this is a particular problem associated with externalities of things like climate change. And with that, we'll stop here. And then there was a wrap-up slide that we didn't get to. But we'll talk a little bit about the problem of elasticity. And then we will move on to calculating costs of nuclear power.