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MODELING THE FUTURE

A Conversation with Stephen Schneider

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MODELING THE FUTURE

Before I start one of my talks, I love to ask the audience how many people in the room think the science of global warming is settled. About half the audience puts their hands up. How many think it's not? Maybe a third put their hands up. How many think it's a stupid question? They laugh and they finally all put their hands up. There's no such thing as all settled and unsettled.

The Intergovernmental Panel on Climate Change—I participated in all four of them plus the two synthesis reports—said that warming is unequivocal. It's absolutely right. Thermometers don't lie, unlike certain pundits, business leaders, and West Wing politicians. Plants don't bloom earlier in the spring by accident, nor do birds come back earlier from migration by accident. Some do not act that way; that's why we average them all up, to find out if the climate coin is loaded—and it is.

Warming is unequivocal, that's true. But that's not a sophisticated question. A much more sophisticated question is how much of the climate Ma Earth—a perverse lady—gives us is her own, and how much is caused by us. That's a much more sophisticated, and much more difficult question. In the last 20 years we learned to answer pretty affirmatively that for the last 30 to 40 years of climate change, it's very likely (which language imposed in the IPCC means more than 90%) that more than half of it is caused by us. This global warming science sounds pretty settled, doesn't it?

Next, you ask, well how much will it warm up in 100 years? To address that, one must consider two fans of uncertainty: natural response to human pressures (the so-called climate sensitivity) and human behavior: how many people are in the world, what our standards of living will be and what technology we will be using. We have an uncertainty factor of about two to three when predicting the future greenhouse gas emissions due to social and behavioral and technological crystal-balling.

Then we have another uncertainty factor of two to three, which comes from the internal dynamics of the climate system: how will clouds amplify or dampen the heating from greenhouse gas buildups, and a whole range of what we call feedback mechanisms. This is what I've been working on for 35 years, and we're still, I'm sorry to say, no closer to resolving it to better than a factor of two to three despite all of our best efforts.

Put these factors together and our projection for the future is that the best we could do is warming up an additional one and a half to two times what we have so far (three-quarters of a degree C since 1850). That's the "best." Not a wonderful scenario, but certainly much more adaptable than the worst published predictions: some 6.4oC warming by 2100.

That still isn't even the worst case scenario, because I can imagine worse that's above a 6.5°C warming: that's a temperature change between the Ice Age and an interglacial cycle—which normally takes 5,000 years—happening in one to two centuries. This would lead to catastrophic outcomes including massive species extinction, super hurricanes, many meters of eventual sea level rise, etc.

Let's return to the is-the-science-settled question? If we're deciding between "we'd really rather not have it, but we can adapt most systems," versus "oh my God, we can't adapt to anything as large as 6°," that would be an ugly, horrible world. The truth is, the science is settled in some things and not in others. The really prescient question, and what matters, is not whether the science is settled, but whether we know "enough" to have precautionary action to try to lighten the weight of our footprint on the earth so that the likelihood of the more serious outcomes is reduced. In other words, can we be risk managers on a planetary scale when we don't have a global government.

We have to have cooperative solutions, since a ton of carbon emitted in Beijing does exactly the same thing to the ecology as one emitted in Boston. We have to make deals, and deals involve trust and cooperation—things we're not so good at. We're wonderful at competition; we're pretty lousy at cooperation. So sure, I ask the scientific question, "Can we narrow those two fans of uncertainty?" But lying underneath it all is how will we get cooperative solutions so we can lower the probability of the highest risks, and that keeps me plenty busy—and in airplanes, generating more CO_2 than my share by a large fraction.

In fact, I'm editing this interview on an airplane right now.

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There's some debate as to the predictive validity of modeling between experimentalists and theoreticians or, in the case of climate, modelers and observationalists. I think it's a false debate. You can't do one without the other.

First of all, there are no observations of the future until it happens and by then it's too late. Therefore, the future is by definition a model. Now, the model itself is our best understanding of how the atmosphere works, how the oceans work, how ecosystems work, how chemical exchanges work. There are all kinds of models: models of social components that try to predict population growth, demographic models that predict population sizes, standards of living predictions from economic models, political models, technological and scientific models, etc. Every one of those is based upon empirically grounded sciences that look at the current and the past of different experiments or societies, and then construct a crystal ball that makes a prediction. The crystal ball is kind of cloudy, but it does allow one to project forward alternative futures under different assumptions of human behavior that modifies the atmosphere. To model successfully, we try to assess confidence based upon how much we believe their structural integrity will be viable over time.

I'll give you two radically different examples. Somebody predicts an eclipse 28 years from now and they do it with an uncertainty of a matter of minutes. This prediction is based on a model, and most of us will bet a fair amount of money that they will get it almost right. It's possible that an unpredicted asteroid will go by and somehow disturb gravity, and screw it up a bit and throw off the prediction slightly. Why is it that that prediction, even though it's a counterfactual, is deemed reliable? Because we have such underlying confidence in the equations of celestial dynamics that we assign a very high confidence within a narrow range. Even though there's always a probability function and there's always some uncertainty that our median, best guess or mode, isn't quite right, the tails of the probability distribution are really tight.

Now let's look at a different type of model, one that tries to predict how people will value species of birds versus the development rate of the economy in a bird-rich tropical country. You can go to that country now and you can take a look at their values. But, in order to know what their values are going to be in 100 years, you have to figure out what the threats are to the birds, as well as how that culture is going to change. To do this, you have to make deep underlying assumptions about both nature of a species' viability and a culture on which you really have only limited empirical data.

You're going to make a prediction because you have to and because it's a relevant question, but your probability function may be so broad that you have little real quantitative information other than the fact that anything from little effect to catastrophe are still probable at more than a few percent chance. Assessments of both potential outcomes and associated probabilities are based upon both mental and mathematical models, which are your best codification of our current understanding, and are to the extent possible empirically grounded.

But the not-empirical question is, how good will the assumptions that you used to construct those models be in the future? Your confidence is going to depend upon how much you believe that the structural integrity of models built from today's conditions will hold in a very different future world.

Think about ladies' hats and Easter. Back in the Easter parades down Fifth Avenue in the Victorian era, it was fashionable to have 30 cedar waxwing bird carcasses across the top of the hat. I don't even think you would find the most rabid anti-environmentalist doing that anymore! We've had a radical cultural change that we don't want to ravage nature for fashion. Was that predictable in 1900? I'm not sure. We always have to be relatively non-arrogant when we're talking about predicting social change, evolving value preferences and technological change. Yet predict it we must, if we want to have some idea about what the space is within which we're operating over time.

I keep arguing, don't be too arrogant about the belief in your models; what you do is make projections, and then you crank a knob to try to avoid the more catastrophic outcomes or the outcomes that don't match your values, but we better be reflexive. That means we had better have what in the language of the systems guys is a "complex adaptive system." We need to always build in knobs so that as we get new information that changes our understanding of the structural bases of models, we can in turn crank up or down our degrees of policy control. But we rationalists, we systems analysts, think that's a great model of reality.

But then I go to talk with members of Congress, and I talk to government ministers in other countries. I discover, often over a good glass of wine, that they think that's a rational measure of good policy, but that they are nonetheless going to go through a five-year knock-down political debate—with the auto industry that wants to make big fat polluting cars, and the mining industry that wants to get the coal and uranium at lowest cost—and when all is said and done, they will reach some political compromise that satisfies nobody. But at least it's progress—and the last thing anybody wants to do is go back in five years and revisit that ugly debate and rekindle, among all these already not very satisfied stake-holders, more reasons for them to be angry.

That is why when we intellectuals say, "Hey, set up a complex-adaptive system, adjust the management knobs as we learn more," politicians say, "Oh no, we solved it, don't reopen festering compromises. Problem's over. Don't take me back there anytime soon."

As scientists, if we think we're going to make a difference in the world, we have to get beyond the rationality of our own inside-the-club thinking in which adjusting knobs and building complex-adaptive systems are the way to go. We have to think about the public as well as the various stakeholders and decision-makers, and figure out how we can make it safe for the honest politician—not always an oxymoron—to be able to build a rational management system that recognizes that very wide tails on uncertainty distribution mean that you have to be able to crank up or down as you learn more; that you can't claim the problem is solved and never revisit an issue once legislation is passed. But we also need to put ourselves in the shoes of those making policy and being buffeted by it as part of our design process.

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The kind of models I use and build in my own research are low-order models that look for emergent properties of coupled systems. First, you take a very simple climate model with low-dimensionality (not a complicated weather model that incorporates every wind and every flap of every sparrow's wings). These are a sort of large-scale aggregation of the energy flows in and out of the earth—the kinds we actually built 30 years ago. There's nothing new there, and they're good for scaling the sensitivity of the planet to pushing on it with doubled CO_2, but they don't give you much detail.

Then we go to an economic model, which is just about as crude: It assumes that the amount of energy we push into the system increases the economy; that if we increase the costs of conventional energy and, thus, lower emissions, we reduce warming but hurt the economy; and that there's some balance between the two. But what happens when you couple them? We sometimes get a surprise.
We took a look at the climate model assuming doubled CO_2. There are many variables that matter in this. Climate sensitivity, for example: How much does it warm up if you double CO_2? That's a big and fairly uncertain parameter. And there are others. What's the mixing rate in the ocean? What's the heat transport in the oceans? All of these are very significant. Similarly, you build an economics model, also with lots of things that matter. What's the learning curve in which costs of renewable energy come down with experience? By how much will the cost of alternatives come down as you invest? Are people really going to prefer consumption to every other form of human value? Then there's the discount rate: Are we going to assume that the present is much more valuable than the future?

All those are parameters we know about, nothing new there—standard in economics, standard in climate studies. My students and I put them together into a climate-economy model, and then asked it what was the probability of knocking off the Gulf Stream in a major warming scenario. The system has a non-linearity in there—a saddle-node bifurcation. What that means is, you get close to the point that when you fall off the table you can't just get back on, you have a partial irreversibility known as hysteresis.

It turned out that all those parameters that mattered to the climate model, and all those parameters that mattered to the economics model, while they still mattered a bit in the coupled model, were completely trumped by two parameters that controlled the behavior of the coupled system. Climate sensitivity was the big gorilla from the climate side, and the discount rate—how much we value the future—emerged as dominant from the economic side.

So, from the coupling of two models, we found an emergent property, which when you think about it for a minute you shouldn't have needed the model to know because it's somewhat obvious. But I did need the model to know, and I did need to put in a non-linearity. Maybe I wasn't as smart as I should have been in advance by figuring it out mentally, but I use models as teaching machines, and I love to couple models together that give you emergent properties that you might, if you weren't arrogant, admit you would not have thought of without the model.

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So, let's put all this together and see what all this can tell us about global warming.

Thus far, we've warmed up three-quarters of a degree C. That's from increasing carbon dioxide by 35%, more than doubling methane, adding chloro-fluorocarbons, etc. Now factor in aerosols—particles, dusts, and hazes which mostly cool us back about a third of the way—although there's a big debate whether this effect takes us back 20% or 60%.

What about the future? Why do we say that the least we could do is go another 1° or 2° more warming? If we froze the amount of CO_2 in the atmosphere at current value, we would not stop the warming for two reasons. First, it's going to continue to warm up at least another six to seven tenths of a degree because the oceans haven't caught up thermally yet with the historic CO_2 increase. This is going to take 200 years or so.

Second, the probability that we're going to freeze concentrations of carbon dioxide tomorrow is about as close to zero as any social forecast I could imagine. If we assume that we will continue to use the atmosphere as an unpriced sewer (even when we price it we will still dump in it, it will just be more expensive) it's very likely that levels of carbon dioxide and other greenhouse gases will continue to rise—for decades at least.

Let's say we wind up doubling pre-industrial levels of CO_2 (we're sort of halfway between that and pre-industrial now), not only will we have the thermal inertia from the warming we've already put in the bank, we will likely have to live through much of this century experiencing increasing greenhouse gas levels concentration in the atmosphere.

In that case, it's pretty hard to concoct a scenario that doesn't warm us up at least 1° to 2° on top of what we already have caused. Even with strong policy rules, it will go well beyond current levels of heat trapping gasses. The most likely plan is to keep it well below what it would have been without controls, not a mythical reduction in emissions below current levels.

How can it go higher than that? Well, there are two fans of uncertainty. One is human behavior and ingenuity. Are we going to double or triple CO_2—or go even further? Or will we get really lucky with technology breakthroughs and thus figure out a way to lower emissions at costs that are politically acceptable? Or, alternately, will there be a world depression, which would also decrease emissions. I guess I'd rather have climate change than a world depression.

In the more likely event that global economies continue their steep growth trajectories, it would be wonderful if we made those technological breakthroughs that make sufficient and cost-effective alternatives to highly polluting current fossil-fuel-based systems possible, but let's not count on it; we can model it, but we'll give it a relatively low probability—UNLESS we make the needed investments and incentives so we can "invent our way out" of this conundrum.

So climate friendly technology deployments constitute one part of the uncertainty. But the internal dynamics in the climate system add yet another fan of uncertainty. If you added four watts of energy over every square meter—that's what doubling CO_2 does—immediately you will evaporate more water, creating more water vapor. Water vapor is a greenhouse gas so that's an amplifier: positive feedback that warms the atmosphere further. But, more water vapor, more clouds. Whiter, brighter clouds reflect away sunlight. That's a negative, cooling effect that stabilizes the system.

Does that mean nature is a stable, homeostatic system? Or is it filled with tipping points and non-linear scary stuff? The answer, of course, is both—depending on the scale, the time frame, and what we're looking at. Quantitatively, however, we don't have a clear answer and there is an uncertainty factor of two to three as to how sensitive the climate is to greenhouse gas forcing. The current on-the-street models tell you that if you double carbon dioxide you're going to warm up somewhere between about 1.5° and 4.5° eventually (200-300 years from now).

But we don't rule out, by a 10% chance, the lucky circumstance that it could be less than 1.5°.

Unfortunately, the sword of uncertainty cuts both ways, and thus there is a very uncomfortable 10% or so chance doubling CO_2 would warm us up more than 4.5° C—which would, of course, be a catastrophic outcome as that is the magnitude of an ice age to interglacial transition occurring in a century rather than 50 centuries as in geological history.

There are still imaginable positive (amplifying) feedback processes that wouldn't be triggered until you get warm enough to set them off. Some examples: melting permafrost dumps methane and gives you a big amplifier; the current tropical forests, so long as you're not cutting them down, soak up more CO_2 than they give off—but some recent literature suggests as you warm up more than a few degrees, tropical forests switch from being a sink of greenhouse gases to being a source; and oceans absorb less CO_2 as they warm. You can't even identify and evaluate or validate these feedback processes at this point in the climate-change process since they won't get significantly triggered until we're a couple of degrees warmer.

Even though a lot of this is theory, it's easy to see that the climate sensitivity on the top end is not very bounded. While we say it's likely (there's at least a two in three chance) that it won't go up above 4.5°, there's a 10-20% chance that we could have blown it already and we'll end up at the catastrophic end of the bell curve of uncertainty.

This is where planetary risk management comes along. What would matter if you warmed up only 1° or 2° more versus 4° or 6° more? Let's start with what has happened already, with a three-quarters of a degree increase. We've seen increased heat waves. The European heat-wave in 2003 that killed more than 40,000 people was totally unexpected. It was the most extreme heat wave in recorded history and the Europeans were completely unprepared for it: the death-toll was so high because nobody predicted that that many people in would be vulnerable.

Was that Ma Earth being perverse? Or was that us overheating the planet? We don't make heat waves: that's part of the internal dynamics of planetary climate system. But they're riding on top of the warming trend, and therefore if a heat wave is a probability bell curve, by moving it to the right you dramatically increase the probability under the right-hand tail; therefore what you do is substantially increase the likelihood of a real doozey. Though we may not have caused the heat wave, we undoubtedly had a part in making it as intense as it was—we can't say by how much since we can't do statistics with only a few such wild events.

What else have we seen?

We've observed that Category Four and Five hurricanes have increased substantially since 1970. It's a natural cycle, say some people in the hurricane center, and certainly some people in the government say that. But if that were the case, if it's a natural cycle associated with internal dynamics in the Atlantic, why did it happen in both the Pacific and the Atlantic? Why is it correlated with the warming ocean temperatures? Why can't those ocean temperatures be explained easily by any natural forces and require at least the last 30 years human global warming to be factored in to make any sense? And why does every thermo-dynamic model of a hurricane say that, all other factors being equal, if you warm the ocean you have to increase the intensity of hurricanes

Theory and empiricism, then, are in agreement. Everybody says the problem's too complicated to assign high confidence, so IPCC said that it's "more likely than not" that the observed increase in hurricane intensity is from the six to seven tenths of a degree warming is due to human-induced warming, and it's "likely" that hurricane intensities will become significantly stronger in the future.

So, if we have warming of 1-2°C we're going to have hurricanes that are more intense and we're going to have more heat waves. But if we get to 5-6°C, we're not just going to have more of the same. The intensity goes up dramatically. The damage from the hurricane goes with the cube of the wind speed.

Ninety percent of the annual damage is done by the 10% most powerful storms. Warming may not increase the number of storms (in fact, it might even reduce that number in some studies), but it will, every now and then, give us bigger, more destructive and more intense storms. Therefore it is not a good idea to warm up very much if you want to reduce the likelihood of those really dangerous storms.

What else is in the forecast?

The forecast says Mediterranean climates will get dryer. What's a Mediterranean climate? Mediterranean area, South Africa, California, South Australia all have Mediterranean climates: these are places that have very little rainfall in the summer.

Climate models agree about warming (although not the magnitude—they agree roughly within this factor of three) but they agree very rarely about precipitation change except in two regions: high latitudes where they all get wetter, because the atmosphere holds more moisture when it starts out cold and gets warmer; and they agree that Mediterranean climates get dryer.

That's not a good thing. Mediterranean climates are already too dry, and they're already hot in the summer. If it gets drier, meaning less rainfall total, and at the same time the temperature increases, you wind up with a pretty disastrous scenario for water in a water-starved state such as California where 50% of the water comes from the snow pack. In the last 100 years, the snow pack has been observed melting sooner, causing more early spring floods followed by and then longer dry summers which require more water for agriculture, industry and fighting fires.

What else happens when you have a dry summer and you crank up the heat? Wild fires—they are a very very big problem in the Mediterranean, as we have seen in recent summers with wild fires in Portugal, a very big problem in South Africa, a very big problem in Australia, and a very big problem in California. Recently, they have even been a problem in the southeast, which is normally not thought of as dry.

This going to be just as true at 1.1° of warming as the 0.7° we have experienced so far. It's just that an extra .4° would bring even more intense fires. What about at 6° more warming? Well, it's also going to be true that you're going to substantially increase the probability of wildfire—you're just going to make that happen more often and the intensity is much much greater.

People like to talk, especially enviros, about tipping points. I too have used abrupt non-linear climatic impacts as a major reason for concern over higher warming levels. What's an example? Flipping off the Gulf Stream. Or melting Greenland; once you induce major deglaciation it's gone, at least for ten thousand years. Some say that there is a threshold: 1.0° more warming, and we're going to melt Greenland.

The most frequent number cited is the European Union's 2 oC above pre-industrial warming as the limit before we have "dangerous" climate change. That is 1.4 oC warmer than now. Indeed, in my own chapter of IPCC we agree that more systems become more gravely threatened above about 1.4 from now, but it is not a strict threshold in any traditional sense, just a risk management judgment for unacceptable risks.

I don't believe any single estimate is a threshold for dangerous climate change—we already have experienced some dangerous impacts in which climate change is partially implicated—(Katrina, the 2003 Euro Heatwave) and more is being built into the pipeline!. But as far as the Greenland irreversible melting threshold, presuming there is one, we don't know if it's 1°, 2°, or more. There is even a small chance we've already committed ourselves to that very bad situation since the ice there is melting faster than any of our current models can predict.

What happens past some tipping point is not known, but it's best described by a probability function—a bell curve. Even worse, we could cross that threshold and not have symptoms on a grand scale for a century, but it would be inexorable and all we could do is retreat from coastlines of a millennium. You would have to be crazy to take the risk that we will luck out on the bell curve and the threshold for deglaciation will be more than 3 oC warming, but that's risk management, not scientific "truth." Another common concern often expressed by environmentalists is that we somehow have "ten years left" before we cross the threshold where we will irretrievably have passed our tipping point. The problem, again, is that we don't know where that point is. And that's just for Greenland.

How about for bleaching of coral reefs? The northern end of the Great Barrier Reef, the warm end. You're probably going to bleach it out with half-degree more warming, and with 1° more warming, lead to very serious mass death. What about the southern end? It probably can go 2° or 3°. So what single number do you pick as the tipping point for devastation at the Great Barrier Reef? You can't just pick one. Again, it's a bell curve that varies across space. All you can say is the higher you go with warming above the present, the larger the number of systems that will be harmed and the more intensely they will be hurt.

My point is that we should not get hung up on rhetoric that says that at 1.2° more warming the world is fine and at l.6 more it turns into a climatic pumpkin. Nonsense. It's not an on-off switch. It's more like a kid's skateboard ramp. That equipment starts upward slowly and gets pretty steep shortly thereafter, and pretty soon it's going almost vertical—when the kids do their jumps and the parents shut their eyes. But it's not an on-off switch—no upward track then a vertical wall.

It just means that the more warmth we add, and the faster we add it, the more difficult it is to adapt—both for us and for nature—and the more damage is done. Speed is very important in this equation since the faster you change the temperature, the lower your capacity to adapt. We can adapt much better when we know what's coming and have time to react. But it's not linear. Every time you add a half degree you don't just add a fixed proportion of systems harm. You add much more, and you increase risk, non-linearly.

I just keep saying, let's not take the chance. Let's slow it down. Particularly since we can fix the emissions balloon over this century at a small fraction of the growth rate of the GDP, though that might still represent trillions of dollars of investments in clean technologies. Moreover, though macro economically it is not a very large reduction in the growth of the economy to get unhooked from fossil fuels this century, it will be a big blow to those who mine coal or make overweight cars and light trucks. So in addition to protecting the stability of the climate, good governance has also to deal with the people who are hurt along the way by policy—primarily with the side payments, so that we get them through the transition to clean technology and not have them endlessly as political blocking coalitions.

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I divide my life pretty much in thirds. One third is education, outreach, teaching, media, talking to Congress, parliaments, premiers, etc. and trying to get people—governments especially—to see this problem as it is and not as it's typically portrayed in the media, which tends to focus on the two extreme, lowest probability outcomes: (1) global warming is the end of the world or (2) global warming is good for you.

The second third of my time is spent trying to understand the science. When I talk about the science, I don't just mean answering questions like "how many degrees does the earth warm if you double CO_2?" That's a very strict bio-geophysical question. I also want to know what happens to the water supply systems of the world if the planet warms by X amount? What would it mean to agricultural productivity, or to sea level, to the intensity of storms and how they impact people? I consider the study of the impacts of climate change just as much a science as predicting how much it will change.

The final third of my professional life—which involves value judgments as much as scientific and technological assessments—is spent asking the question: "What do we do about it?" That is, of course, a very difficult question because it involves inventing our way out of the problem on the one hand, but not waiting 20 to 50 years to do that on the other.

What is the sequencing of the so-called low-hanging fruit? The first step is performance standards for refrigerators, air conditioners, automobiles, machines and housing efficiency. That gives you a very fast payback.

Second step: public-private partnerships where we try to get the private sector to invest in the development and deployment of renewable and other low-carbon-emitting alternatives. They have return on investment criteria that are often too stringent to get a lot of the billions of dollars that need to flow into development, so we will need some federal, or state, and city financial pump priming, along with the bigger private foundations.

Third step: you can't keep dumping your tail-pipe waste and your smokestack waste and changing the land surface—all modifying the atmosphere—for free, as if it's an unpriced sewer. Sooner or later there has to be a shadow price on carbon. Whether it's a tax, a cap and trade system—somehow you have to make the polluter pay, and we have to take a look at the efficiency and effectiveness of those techniques.

But there's a component in this evaluation that I pay particular attention to that most of the economists do not. That is, if we increase the price of doing business by including a tail-pipe charge for our messing up the climate (and there should be one, because we are messing up the climate), the fact that it might cost me a thousand dollars a year in extra expenses might affect the quality of what restaurants I patronize and which grape I drink.

But, what will it do to a poor person? It might affect the quality of protein on their family's table. It's a dilemma. On the one hand you have a moral principle: the polluter pays. On the other hand, the relative fraction of my disposable income that that would represent is much less than that of a poor person in a hot country, or even a poor person in the United States. Energy costs are in that sense a regressive tax.

You cannot hold the sustainability agenda of the planet hostage to artificially low prices of commodities like food or energy, any more than you can allow what the first President Bush said at the 1992 Rio Environment Conference: i.e. "the American standard of living is not up for negotiation." In fact, if we're talking about poor people demanding equity, and therefore having per capita equality with us as polluters, we're talking about quintupling CO_2 in the next century. That's unacceptable from the sustainability point of view. On the other hand, when we're saying that we will make the world safe for Hummers and SUVs at any and all costs, that's not morally acceptable either.

So the question is, how do you make deals where the over-consumers (us) work out a deal with the over-populated and the not yet fully consuming group (developing countries), so that they don't just repeat the Victorian Industrial Revolution with the sweatshops, dirty coal burning, internal combustion engine, etc.? The answer is that these economies in transition need to leapfrog right over it to high technology. Exhibit C: cell-phone. If you go into Central China, they talk to each other on cell-phones—well, so do we (we being the Europeans, Australians, Americans—the OECD type countries).

But how did we learn to communicate? We used mega tons of materials: copper wires, and we used energy to do it. China has not done that to our scale. Their cities are wired, but not the countryside. They literally leapfrogged over the

Victorian Industrial Revolution to high-tech with regards to communication via cell phone technology.

We have to get them to do the same with primary energy and transportation, so that they can produce the kind of economy that gives them a decent standard of living without polluting the planet to a point where they and much of the rest of the world suffer a standard of living decrease. It can be done. It can't be done by China alone, or India alone, or us alone. But it can be done by good faith bargains—and that brings us back to that sine qua non—cooperation and skills-transfer.

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We've become a sprawled society and urban revitalization also has to be part of the climate solution. One might not think of sprawl as a climate change problem, but it really is. The farther and farther away from work we live (especially if we insist on going back and forth in single-driver 6,000-pound off-road vehicles!) the greater our contribution to climate change. It's just not effective, even if true, to just wave your finger at people and say, "Don't do that, you're a sinner."

You have to give alternatives and say, Well instead of that, there's this. We'll make alternative transportation, and by the way the plug-in hybrid is a ton of fun, the car's a beast, goes from zero to 60 faster than your monster—it's a real cool car, your friends will think you're impressive and you'll be getting a hundred miles a gallon—and that is all well within the technical feasibility and affordability of the next 20 years. But for any of this to happen, we are going to need a sea change in the industrial mentality.

Instead of producing what everybody currently gets because they've already paid for the tools to build it, why not try something new? Why not go to ceramics? Why not go to mixed electric-mode cars? This recalcitrance is the product of what I call the 'NIH syndrome': Not Invented Here. And if there's any hope of getting over it, we need government action that makes business as usual cost more and trying something new cost less. It's amazing how that tends to stimulate the smart ideas—we are a culture that knows how to follow the smart money.

The government stimulates science by deciding to whom to give research grants or other incentives. It also stimulates science because if the government says we really do want to have lower emissions, and we know that we have to have nano-tube solar collectors or DC transmission lines—or whatever crazy, new, brilliant breakthrough that I'm hoping will happen—somebody has to fund that.
The government doesn't spend an infinite amount of money on all professions or breakthroughs just because they are made. There is some targeting going on, and if the targeting is toward doing the underlying science that we need to bring

down the costs of some of the potentially really earth-saving technologies, that's fine with me.

After all, the object of government is to try to help improve the quality of life of the citizens of the country, and hopefully the planet too. Sometimes that involves targeting investments. We certainly target investment for the study of cancer and investments in national security. Why not target investments in sustainable development and a safer environment?

Those are all legitimate roles of government, and of course the classical political argument is about where to draw the line in the sand between encouraging private rights so that people can have incentives to invent and at the same time charging when you're really a scofflaw to the planet by just dumping your wastes for free in the atmosphere. And finding that bottom line is the politics of climate change, but it's much more complicated than that since it has to be internationally negotiated as well since the atmosphere is shared by all of us—and abused by all of us in unequal shares.

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When we think about technology and climate change there are three aspects that we need to consider.

First, is it feasible? There's already a debate. Some people say that we have to invent completely new technologies and others (myself included) are betting that the implementation of existing technologies—especially efficiency, improved renewables and so forth—can probably solve more than half the climate problem without doing more than doubling the cost of energy. That might sound like a lot, but it would have a very small impact on the overall economy. Total number of dollars in a bad case could be trillions, but the total cost would only be a small fraction—something like 10%—of the growth rate of the GDP (the standard measure of the world economic output).

In comparison, GDP is typically projected to grow for the next century at about 2% a year, so if you run the numbers you'll see that trillions over that long period are really a small price to pay for long-term climate stability. In this scenario, you'd end up being 500% richer per capita in the world in 2102, with only increasing CO2 by about 50% over the pre-industrial natural level vs. being 500% richer per capita in 2100, but more than tripling CO2 and facing all the big risks associated with that unprecedented level of disturbance to the atmosphere.

Macro-economically this sort of thinking shows climate policy in which more expensive systems that are cleaner are phased in over decades is not a big problem. Micro-economically, however (if you're in the coal business or you build big cars), it's a big problem because the higher energy prices will price you out of the market. We have feasible technologies, but have some cost issues—and certainly a distributional issue of winners and losers of the policy—that would have to be addressed in the legislation for regulations.

The second consideration is: Can we lower the costs of getting unhooked from fossil fuel burning? If you want to get the unit costs of those alternative technologies down to the current cost of wind or coal, it's going to require a big R&D program. We need to invent our way out of this dilemma by experimentation with battery vehicles, solar thermal power plants, safer nuclear, storage capacity for wind and lower losses transmissions lines.

Where will the tens of billions of dollars needed every year for the next few decades come from?

That will take public-private partnerships. The private sector will invest when it sees a chance to make money, but it's looking for incentives. There are two kinds of incentives: (1) charging for pollution and (2) rewarding investment in clean technologies.

First, something like tailpipe dumping fees would make standard energy consumption of coal, gasoline and oil cost more, giving companies an incentive to invent their way to higher profits via cleaner or more efficient systems. Second, direct subsidies—tax breaks, investment guarantees, investment grants, prizes—all would give people incentives to get that combination of brilliant private inventors and investors together.

Then of course there's the third factor, which is the politics of protection of the status quo. The cutest example to describe this is a scenario involving the always-popular Martians—I love the Martians because they're completely impartial. Imagine that the Martians come down and give us the plans for the best hydrogen fuel cell car you can imagine, at a unit cost comparable to our standard car. They even give us a new catalyst that's going to do reforming at the gas pump from a biofuel like ethanol. Even if we received this visit tomorrow, it would take 25 years or so to take advantage of the new technology gift.

Not only would we have to develop the infrastructure and get people to adopt it, there would also be a prolonged battle with blocking coalitions in the coal, automobile, and oil industries. This is to say nothing of the blocking coalitions of ideologues who would fight government incentives and subsidies, saying that the private sector and the free-market should decide, while ignoring the damages done to the commons by unregulated use of the atmosphere as a free sewer to dump our smokestack and tailpipe wastes.

This isn't just a problem for people who care about the future of the planet; we have to actually figure out what the cultural symbols are, what the hot buttons are that get society to reject the arguments put forth by opponents of change, and embrace change that's beneficial to the vast majority.

My view is, you have to buy them off. Economists have a much better name: "equity side payments." Some of us are a little more honest and call them political bribes and I, for one, am perfectly willing to pay them. I think that nobody builds an SUV or mines coal to screw up the climate, but that's exactly what they're doing. They're essentially holding the sustainability agenda of the planet hostage for the sake of perpetuating their grandfather's line of work. So planetary health requires a change, but fairness says we help them through the transition to cleaner replacements.

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I am not motivated in any of this by knowing the truth. I don't know the truth—nor does anyone else—about the future. What I teach, when I teach my Environmental Literacy course at Stanford, is to help confused students sort out how to tell this guy's claim from that guy's contradictory claim. I say, well, if a new dentist moves into town and hangs up a shingle that says, Painless Dentistry, what are you going to think? What about a new shop claiming to sell only Bargain Antiques? Or what do you think about a country that calls itself the Democratic People's Republic of Such-and-Such?

When the claim is in the title it's usually because the opposite is the truth. Check it out before buying it. You have to watch out for the myth-busters and the truth-tellers or the deniers of any risk or the ones who have absolute thresholds below which we're fine and above which everything ends—none of that is a very good description of our more probabilistic knowledge of future events and concerns.

What we know is that the warmer we get the more we add systems at risk and the more intense the impacts. We know that we need to slow down the rate at which we increase that risk without having to know precisely where these many impacts thresholds are, because they are not precisely knowable in advance. They are experiments we're performing on Laboratory Earth and—as I said in my book of that title from 1997—it is a "gamble we can't afford to lose."That's how I try to frame the problem.

I was told by an environmentalist the other day that using the language of tipping point phenomena (i.e., we must move now or we'll be irreversibly lost) is a good way to get people's attention. I said, well, that may be true for some phenomena, but we don't know where the points are. We can guess, but what if we're wrong? What if we say that we have 10 years and we don't do much? If nothing much has happened in 10 years, what then? Another tipping point 10 years later? People are going to remember what you said 10 years ago and your warnings are going to carry less and less weight and your predictions less credibility.

We live long enough that you have to be able to answer for your predictions. I much prefer to say that it just gets increasingly difficult to deal with the more and more warming we keep adding to the system. As with environmental literacy, watch out for the myth-busters, the truth-tellers, the ones with the simple answers from either side. You can almost always believe more somebody who's talking in ranges or subjective probabilities or bell curves, but at the same time isn't shy about saying that there's some real risks out there we need to mitigate.

Another reason I have opposed the "ten year framing" is the possibility that society will go on with business as usual and do nothing much. Then what? Do we say in ten years all is lost? That is very counterproductive—what I call the "On the Beach" mentality after the Nevil Shute novel that was made into a movie. In it, the radioactive cloud from the nuclear war in the north is moving to Australia and they have months to live. Given that final inevitability, why not go out and race your car and go for derring-do of all kinds and get killed having fun? You're going to be dead anyway soon enough, and radiation sickness is a horrible death.

But that's not the right metaphor for climatic thresholds. Every single thing we do that slows warming down is better than doing nothing. But even if you fail to get adequate measures implemented soon, you don't give up, you keep trying to prevent it from getting higher and worse. That's my style, and not easy to sell in a sound bite, but I think you have to tell the truth. To me we don't really know what the absolute thresholds are, so let's not gamble that we might get the most dangerous ones, not because we're sure, but because we're prudent.

As for the climate denialists, we've seen their kind before—and gladly they are a vanishing breed in both smoking and global warming, though a few prominent ones are still out there spouting. Just remember, watch out for the myth-busters and the truth-tellers and listen to the careful ones talking in ranges and bell curves.

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