L. RAFAEL REIF: Good afternoon, everyone. What a nice crowd this afternoon. Welcome to the MIT's Compton Lecture. And we're looking forward for a very lively question and answer session right after Mario Molina's lecture.

First I'll give you some context about this lecture series. In 1957, MIT established the Compton Lectures to honor the memory of MIT's 10th president, Karl Taylor Compton. He led MIT for almost a quarter of a century-- that should be reason enough to honor him-- in two roles. First, as president for 18 years, and then, as chairman of the MIT Corporation.

He guided MIT through the Great Depression and World War II. He helped MIT transform itself from an outstanding technical school for educating hands-on engineers to a much broader Institute. A distinguished physicist, President Compton brought a new focus on fundamental scientific research, and made science an equal partner with engineering at MIT.

During World War II, he helped create a partnership between the federal government and America's research universities. A partnership that has been instrumental in driving the nation's economic growth for more than 65 years. President Compton was also known for the scope of his understanding, his integrity, and his record of action in service to society. So it is fitting that we honor his legacy with a speaker who embodies these same qualities, Dr. Mario J. Molina.

As a pioneer in atmospheric chemistry, Dr. Molina has many distinguished titles and honors. Today he serves as Professor of Chemistry and Biochemistry at the University of California, San Diego, and at the Center for Atmospheric Sciences at the Scripps Institution of Oceanography. He's also Director of the Mario Molina Center for Energy and Environment in Mexico City, which focuses on reducing air pollution in rapidly growing cities. He's a member of the National Academy of Sciences and the Institute of Medicine. And in 2013, Dr. Molina received the Presidential Medal of Freedom, our nation's highest civilian award. A member of the President's Council of Advisors of Science and Technology under President Clinton, and now again under President Obama, Dr. Molina also serves as a climate policy advisor to the President of Mexico. As a member of the faculty, of the MIT faculty, from '89 to 2004, he attained the rank of Institute Professor, and he's also served on the External Advisory Board of the MIT Energy Initiative from its earliest day.

Mr. Molina's extraordinary career illustrates important things. The value of basic science, the power of persistence, and of course, for those of you postdocs in the room, the genius of postdocs. In the 1970s, as a postdoc at UC Irvine, Dr. Molina produced groundbreaking fundamental science about the role of chlorofluorocarbon gases, or CFCs, in depleting the earth's protective ozone layer. Together with his colleagues, he recognized that this discovery had profound real world significance for humanity's future. In 1974, when they published their findings, the scientific community pushed back. But Dr. Molina and his colleagues pushed harder. They briefed their fellow scientists. They held press conferences. They lobbied Congress. Dr. Molina spoke out with confidence and clarity over and over until his warning was clear. And he did not give up until the nations of the world signed the Montreal Protocol that banned chlorofluorocarbons for good.

In 1995, while he was a member of our faculty, his early work on CFCs brought Dr. Molina and his colleagues the Nobel Prize in chemistry. But perhaps the best prize was his impact. Today the Montreal Protocol is regarded as the most successful global environmental treaty ever. The Antarctic ozone hole is slowly recovering, and although the treaty was not created to slow climate change, studies now suggest that, if it had not been signed, global warming might now be twice as bad.

In short, Mario Molina is an MIT icon, someone who at every turn has exemplified this community's highest values and aspirations. And last year, Dr. Molina was a driving force behind the campaign by the American Association for the Advancement of Science to make a dramatic difference in public awareness about the threat of climate change. His talk today is titled, "Climate Change: Science, Policy, and Communication." And his perspective is particularly welcomed as we continue our campus conversation about the most effective actions to combat climate change.

Please join me in offering a very warm welcome to Mario Molina.

[APPLAUSE]

MARIO J. MOLINA: Thank you very much, President Reif. It's an honor to be able to present to you this Compton Lecture. And I'm very pleased to be back to MIT, and to have a chance to talk with my friends and colleagues. In fact, I had some very nice conversations already with some faculty and some students. I mention that because I might repeat some of the same arguments here that I had earlier in the morning. So I apologize, in advance, to those of you who heard them already.

So I will be talking about science and policy of climate change. Let me start with this work that President Reif mentioned already, which is a project which we did in coordination with the AAAS. The idea being to draft a relatively short statement on the science of climate change. It was not really easy to do because we had to be very careful not to exaggerate, and so on and so forth. But we did manage to put something together. You can see some very well known scientists there, including Kerry Emanuel, Professor Emanuel, who's present here. And anyhow, we came up with a few conclusions. This is just a very brief summary.

What I want to do is the following. Rather than looking directly at these conclusions, I'm going to refer to three or four myths. That means misunderstandings of the public at large.

And the first one is connected to the first conclusion here, namely the myth is that the science of climate change is not really that well established. Some scientists think that it's something to worry about, but many other scientists think that it's really exaggerated, and we shouldn't worry that much about it. I'll mention the other two or three myths, as I will discuss them a little bit later. The second one is that, okay, well let's suppose climate change is in fact a worry, but it's really something for the end of the century. We shouldn't do anything now. Let's leave that for our grandchildren to be a worry. So that, again, is not factually correct. And perhaps the third one I'll mention here has to do more with economics. This group, that when we developed this document, the idea was it was only a group of scientists. But we were already communicating, of course, with economists, but this third myth is that, even assuming that climate change is a worry and that it's already beginning to affect us, but it involves the use of energy, fossil fuels, and it would be so expensive for society to do something about it. Forget it. It's just something we'll have to live with. So that's a myth as well, and so I'll be talking a little bit about each of them.

The first one . Well, this is now a little old, but it's very clear from some surveys that have been published in the literature, not just one, but several, and the interviews and so on, that the majority of experts agree that climate change not only is happening, but it's mostly a consequence of human activities. But there are, of course, a few scientists that disagree. Fortunately, they are very few. And I should clarify that it's not that these few scientists have been ignored. Their arguments have been discussed when they make sense, and discussed in the literature, and so on. And the consensus is that they really don't-- shouldn't be a worry.

One of the worries, perhaps, is that one of those scientists is very well known and was here at MIT for many years. When I was at MIT, he was my neighbor in the Green Building, and that's Dick Lindzen. And it's a worry because he's a very well established scientist and so on, and his arguments are very often used by the deniers, people that question this. And we were very good friends for a while until we started to discuss climate change [INAUDIBLE]. But we did communicate quite effectively, of course arguing more from my thermodynamic perspective, rather than on atmospheric dynamics. But eventually I told him, look, if you have these clear arguments, you should be able to publish them. Of course, you'll get some criticism, but they will be reviewed, and if you are right, you'll be very well known, even better known than you are now. He didn't like that argument, so we haven't communicated since then.

But anyhow, the point is that it's a very well established portion of the scientific community. And let me just allude to it, going back just a couple of years-- an op-ed in the Wall Street Journal. Here it's signed by 16 famous scientists. One off them, in fact, Dick Lindzen. But the other 15 are not climate scientists, okay. And I happen to know two or three of the others, and I wouldn't recommend reading. Certainly not about climate science, but even in their own specialty.

[LAUGHTER]

But you see here that they question this. Well, fortunately, some of my colleagues replied. And it's sort of obvious. You can read the first sentence. If you have a heart attack, don't go to your dentist. And that's more or less what happened. I would only quantify that, because my dentist is a very reasonable guy, and he would immediately tell me, go on and see your cardiologist. But these scientists don't quite behave that way. And anyhow, this argument was very well discussed.

But here's the point. The main worry is that this-- what I'm calling a fact of the consensus of the scientific community-- is not well represented in the media. And, again, this is now a little old, but the media coverage has been very heavily biased toward this idea that there's a lot of disagreement. And in fact, some measurement shows from years ago that the bulk of the reports were really indeed very biased. But we know now that this is really a result of a very well financed public relations campaign, something that was done on purpose by some interest groups. And this fact has been rather well documented.

Let me just point out this one book that's called "Merchants of Doubt" that was written by Naomi Oreskes and Erik Conway. Naomi was a historian in UCSD in San Diego. But recently she moved to Harvard. But what they found out is that it's actually the same people, not just the same idea. But some of the same people that were doing the public relations campaign with the tobacco industry, they were sort of hired, or they worked again, with climate change. In fact, I understand, I believe, there's now a movie about the "Merchants of Doubt." I haven't seen it yet, but the book is quite interesting because it really documents this public relations campaign.

What's the consequence? The consequence, of course, is that the public perception is biased because of the coverage in the media. And again, this might be a little out of date, but the public responds to whatever comes out in the media.

But to be a little bit more up to date, there are, again, different surveys. Depends on how you ask the question and so on, but in this particular one from the Pew Research Center, what the survey shows is the ups and downs. But 2/3, according to Research survey, 2/3 of the public, chosen at random, do agree that the earth is warming. But less than half think that it's connected with human activities. And that's in fact what happened in Congress. Congress recently passed a resolution finally accepting, okay, climate change is here. Something is happening. But not accepting that it's connected with human activities. So Congress is very much along these lines.

So what I want to do next-- I know that some of you here are really climate science experts, not only students, but faculty. But nevertheless, I'm going to repeat just some very basic science, just to be able to explain in clear terms why is it that the science-- the basic science-- is well established.

So let me just start with this picture of our planet. The atmosphere is what we are affecting, but you don't see the atmosphere, because it's very thin. It's like the skin of an apple, and it's transparent. But we are indeed talking about a global problem, because if you release some gases, say here in Boston, that remain in the atmosphere for some time, they mix within months in the northern hemisphere. And maybe it would take a year and a half, or two or so, to mix also in the southern hemisphere. So for gases or species that remain in the atmosphere for a few years, it doesn't matter where they are released. So that's why we're clearly talking about global problems. But the point I'm trying to make here is the atmosphere is sort of fragile. Because there's also the idea that, how can possibly-- human activities-- how can they possibly affect the entire planet? Well, that's what I'm explaining right now. The atmosphere is fragile.

And so this is a worry that started already in the 19th century. So just very briefly, I won't go into details, but just in the first half. Fourier was the same person with the Fourier Transformer. Of course, more famous in mathematics, but he already worried about what determines the temperature of our planet. How does a climate function? And he got some things right, of course, that the sun is what provides us energy, and that our planet uses energy. He thought the stars would also contribute. That's where he didn't quite get it right. But anyhow, the point is that the science started already that long ago.

And then it was John Tyndall who realized, and measured, the presence of certain compounds in the atmosphere. That there is more proportions that absorb infrared energy, and this was an important contribution for the explanation of the actual temperature. The average surface temperature of the planet, because measurements otherwise were indicating that it should be much smaller, but the presence of these gases is what was affecting them.

And just the last historical note here. Arrhenius-- which for those of you chemists, Arrhenius is very famous. Not only because of his great constant, the Arrhenius equation, but because he's also an electrochemist. That's how he got the Nobel Prize, in chemistry. But it was already towards the very end of the 19th century, and he had already sort of used this knowledge that was developed previously, and correctly assessed that CO_2, carbon dioxide, was going to increase because of human activities, and that was going to affect the climate. Perhaps what he did not get right, from the current perspective, is that that would be a worry. Instead, he thought that would be something good for the planet. But he did some calculations, some canned calculations at that time, and came up with a surprisingly accurate prediction of how much would the temperature change if the amount of carbon dioxide were to double in the atmosphere.

So all I'm pointing out here is that the science goes back quite a bit of time, and this is science that is now well established. But let me explain that even further with this graph. Just in a few words, how does the climate of the planet function? Well, the planet receives energy from the sun, and it loses energy in the form of infrared radiation. It receives energy in the form of mostly invisible radiation, and it, for a long time-- millions of years-- it has reached thermal equilibrium. That means that the amount of energy received is practically the same as the amount of energy that it loses. So that's well established. But we have now an equation there that describes-- what was measured initially experimentally in the 19th century, could not be explained-- it describes the shapes of these curves, which of course is important for the description of the climate. And that is Planck's equation. I'll come to that in a minute, but I have two other equations here. Einstein's photoelectric effect, which is, by the way, what gave him the Nobel Prize. It was not relativity. And just an integration of the equation, which points out that the amount of energy emitted-- actually, it's power, energy per unit time-- is very sensitive to temperature.

But coming back to Planck, he came up with that equation, and the interesting thing is that revolutionized physics. It's of course the beginning of quantum mechanics. And quantum mechanics is very well established now. Who would question its existence now? But it's the same equation that describes how energy is emitted by our planet. That, namely, the energy comes in packets, and the same thing happens with radiation, photons, and so on. So all that became part of the nature of science, very early in the 20th century. In fact, at that time, just a few years earlier, what was in question is the very existence of molecules. Because some scientists thought that there was not enough evidence that they really existed. So that date was not that long ago. So that, nobody would argue today about the existence of molecules, except possibly some politicians.

But let's move on. I'll just describe this briefly. This is-- most of you must have seen it. This is the natural greenhouse effect. Because if we merely use Planck's equation, measuring how much energy arrives to the planet from the sun, and if it receives that energy on the surface, the temperature one calculates is about minus 18 degrees Celsius. We wouldn't be here. The planet would be frozen. So the fact that the actual temperature is more than 30, 33 degrees Celsius warmer than Planck's equation would describe, has to do with the atmosphere. And the conclusion is that that temperature is in fact reasonable, but not for the surface of the planet, but somewhere much higher up in the atmosphere.

So here is what happens, just describing in a few seconds the nature of climate change. These are percentages. So if you call 100 units the amount of energy that reaches our planet from the sun, about 70 of those units is what warms the surface. 30 get reflected. But if you look at what goes out in the form of infrared radiation-- 49 plus 9 plus 12-- it's again 70. So the planet is in thermal equilibrium. But the point is that the fact that these gases-- the greenhouse gases-- are present in the atmosphere, they function a little bit like a blanket. And what does a blanket do? It doesn't quite sort of trap the heat. All the heat, all the energy received per unit time, leaves the planet. But what happens is the surface temperature has to increase because the atmosphere absorbs infrared radiation. And so you see that it has to emit more than twice the amount of energy than it receives, because, of that energy emitted by the surface, most of it comes back. And how can it possibly emit that much more radiation? That it does by increasing the temperature by these 33 degrees. So that's what a blanket normally does. It doesn't quite trap the heat in a human body. It lets all the heat out eventually, but it increases the temperature at the surface. So this is very well established.

And to take it one step further, because I sometimes present this also to the general public, which is not necessarily very familiar with the nature of the atmosphere. But just in a very quick, very brief summary, describing the composition of the atmosphere in a way such that, let's assume, the entire atmosphere is at the same pressure as it is here at the surface. We know, of course, that pressure increases very rapidly with altitude, and that's why you cannot breathe on top of Mount Everest. But if it were all at one atmosphere, it would only be eight and a half kilometers high. But the point is that if you look at 1% of that-- that's the second bar-- and carbon, nitrogen, oxygen, these are all gases that are transparent to visible light. And that's why the energy from the sun reaches the surface, except the amount that is reflected by clouds, or by the surface.

But there is a smaller amount-- a lot less than 1%-- of gases that do trap infrared radiation. And that's mostly water vapor, and in this case, carbon dioxide. There are a few other greenhouse gases, methane, nitrous oxide, and so on, but let me just focus on carbon dioxide.

So there's very little of it. It turns out that water vapor absorbs about 3/4 of the radiation emitted by the surface, properly speaking, and carbon dioxide the other 1/4. So one might think, well, the main infrared gas absorbed-- the main greenhouse gas-- is water vapor. And that's indeed the case if you just measure the amount of energy absorbed. But if you think a little bit further, where does that water vapor come from? Well, the planet has practically an unlimited amount of water, but liquid water in the oceans. So only a little bit of that is in gas form. Well, what happens-- you know the water cycle-- water evaporates. It becomes a gas, a vapor, But as air [INAUDIBLE] rises, it cools. And then the water condenses, and that's why you have rain and snow. So there's relatively little vapor, but it's very temperature sensitive. Again, those of you who have taken physical chemistry or physics, the Clausius-Clapeyron equation describes how much vapor can you have in equilibrium with the liquid. So the point is, for the atmosphere it's a relatively small amount.

But here is the thought experiment that you might want to carry out. If you removed, some how or other, the stable greenhouse gases, say CO_2-- so that means that you would have 1/4 less absorption of infrared radiation from the surface-- then the temperature of the atmosphere would certainly drop. And you can see that, with ice ages and geological times where there was less CO_2, the temperature dropped significantly. That means that the water vapor would begin to condense.

So the point is that water is there as a feedback mechanism. And if you removed CO2, water vapor would condense almost entirely in a matter of decades, and we would have a frozen planet. There would be no life on earth, and so on. So that's why CO2 is labeled the thermostat of the planet. CO2 and the other greenhouse gases.

So far, it's just a very brief summary of the natural greenhouse effect. But I just pointed this out because this is the very well established science. You can teach that even in high school, or in college, that there's not much question about all of these scientific facts I just described.

But now let's move on and see what happens with human activities. And here on a time-scale of 10,000 years, you can see what has happened to the concentration of these greenhouse gases in the atmosphere. It only goes up. You can sort of pin the initial of that change to the Industrial Revolution for CO2. Why? Because it's what you get burning fossil fuels. And there's a lot of activity very sudden. So the amount of carbon dioxide has increased. It's now over 400 parts per billion.

I should have pointed out in the previous graph-- let me see if I-- Okay, let me just go back for a moment. I forgot to mention that just the amount is measured normally not in percentage, but in parts per million. But the point of showing the last curve-- the last bar, sorry-- which I forgot to mention, just to show again for an audience which is not here, but if you don't have a good sense of the amount of gasses that you have-- If the amount that you have in the atmosphere-- for it be condensed as a liquid or as a solid-- the amount of CO2 would only occupy four millimeters as dry ice. Okay, so there's very little of it. The amount of water is just a couple centimeters. Plus, if it's in the gas phase, it's a little more.

But coming back to where we are right now, it's parts per million. And you can see how it's gone from a little over 250 all the way to 400. That's a big change.

And what about methane? Again, just briefly, methane is also a consequence of this change of human activities, because it's produced by enteric fermentation. But it'll produce it in the absence of oxygen. Where do you have that? Swamps, rice paddies that are flooded with water, and also the digestive system of ruminants. What's that? Cattle. Cows. And so, when they eat grass, they digest it. And since there's no oxygen in their blood, they make methane-- both sides. So that explains the sudden increase, because of the population increase. Okay, so it's clearly something not directly emitted by humans, but by human activities. And these are two very important greenhouse gases.

Okay, let's talk about some more measurements. Temperature, you can choose different times case. But here, I choose the same one, roughly 10,000 years. And of course it changes, goes up and down as one expects, because of all the effects of various issues on the climate. Solar activity and so forth. Those are relatively small. You can see that the average surface temperature hasn't changed that much over this period. Maybe half a degree or so. But then again, you suddenly see, in recent times, a sharp increase.

Why? Well, if you follow the basic science, it sort of makes sense, because you have a sudden increase in greenhouse gases, so this is not all that surprising. But nevertheless, you can ask the question, what is the scientific evidence that these two measurements-- see, this is a measurement, and CO2 and methane are also measurements-- that they're connected? And of course, the science tells us that they are indeed connected. And one way to summarize it is by talking about the report of this Intergovernmental Panel on Climate Change that you surely heard about, the IPCC. This is a group of voluntary scientists, maybe a thousand, a few thousand. But just a few hundred really do most of the work. And they publish, every four or five years, a report summarizing what is out there in the scientific literature.

And so, this is the last one, appeared just last year. And the previous one, five years before, they had already answered that question. What is the connection between temperature change and changing composition. They said, well, yes, it has to do with human activities. But we are not entirely sure, because climate is a complex system. There are so many variables that affect it, some of them nonlinear, and so on, so we're not entirely sure. But we can sort of say that there's a 90% probability that the temperature changes indeed are a consequence of the composition change.

And then, four or five years later, now they increased that to 95%. So yes, it's possible that this temperature jump is just by chance, natural, but it's sort of unlikely. There's a 5% probability maybe. So that's what the consensus of the science is. The scientists are not claiming absolute certainty. It's a matter of probabilities.

And let's move now to the next myth, that it's only something to worry about at the end of the century. Well, no, things are already happening. You know about ice melting in the North Pole in the summer. That's now fairly clear. But there are other worries, which I won't show in much detail. But there are floods, there are droughts. This is what we call extreme weather events, and according to this graph, they are becoming more frequent.

There are some criticism of these figures, and that some people point out. Some scientists, they claim, well, look, it's just because now there's more. The population has grown. It's more vulnerable, and that's why it appears that there are more, but in fact that might need not be the case. But if you look carefully, indeed there are more floods because it's raining stronger. It rains more. The full amount of rain hasn't changed that much, but that's why you have floods and droughts. So that explanation does not fit the actual observations.

But nevertheless, it's until a few years ago, the scientific community, very sort of conservative, would say, well, we don't have enough evidence. But that has changed. In recent years, there are a number of papers that have published this. And the point is to present it in terms of probabilities. Furthermore, you don't claim-- let's just use one example-- you don't claim that an event, such as Hurricane Sandy, was caused by climate change. But it's the intensity. The intensity is likely to have increased because of climate change, because of human activities.

And where this is very clear is if you look at extreme events like heat waves. And again, this comes just from measurement. Satellite measurements of temperatures, you pick up just some mid-latitudes, and you measure temperatures. Actually, you plot the temperatures measured by the satellites as a function of time, and you can see how these sort of [INAUDIBLE] begins to shift to the right. That's a consequence of this observed temperature change. And if you were to define a heat wave as three standard deviations away from the average, or the median, because of the shift in these curves, it's now much more likely, of course, to have a heat wave than it used to be some years ago. So, again, this is just from measurements.

Okay, so let me move on rapidly to the next question, which is, can society do something about it? If indeed there's a worry, if things are already happening, should we do something about it?

So I'll start with this graph, which shows the Copenhagen Accord. There are annual meetings organized by the United Nations. The United Nations Framework Conventions, they are called. COPs, Conference of the Parties. And this one was interesting, in 2009. I happened to be there with President Calderon of Mexico. But what made it interesting is there were something like 120 or 130 heads of state. They all showed up. And it was nice, I was able to sneak into some of the discussions. Not all 100 were talking to each other, but just smaller groups. But what is amazing, they sort of agreed that it would be good to attempt to hold the global temperature increase to less than two degrees. Not exactly because that's what the science tells us, but it is what seems reasonable. It would not be too costly, and this way you would minimize some of the larger risk that I'll go on to in a minute. But this is just an accord. It did not become an international agreement, because the negotiators didn't agree. Their job is to negotiate, not to pass agreements. Anyhow, so this is just something-- just a goal that society has.

And the question is, is it reasonable? Well, it's very challenging. If you look at emissions versus time, and here is Carbon dioxide with a small e, equivalent. So that is an attempt to put all of them on the same scale. Methane, nitrous oxide, and so on. Well, the business as usual curve, which is the blue curve, keeps increasing, because of economic development, particularly developing countries. Of course, their economies are growing fast. And that's where we are. But if you wanted to reach these two degree goals, you would have to drop by 50% in just a few decades or so, the emissions. That's a huge challenge, and the question is, is that feasible?

The answer is, in principle, it is. Here is one way to look at it from my colleagues at Princeton, Steve Pacala and Rob Socolow. It's the same schematics. You have emissions, and BAU is business as usual, and we are now above the green part of it, and you need to bring it down to the blue part. But the way to look at is, you have to do these so-called wedges. It can be done, but there's no magic bullet. You have to do many things at the same time. Such as, using energy much more efficiently, using renewable energy, and so on. Even carbon capture and storage, which is a way you keep using fossil fuels, but not releasing the carbon dioxide to the atmosphere. That's still too expensive at the moment. But you can see all these various things that would need to be done, including, of course, forest management not to keep deforestation of tropical forests.

So that means it could be done, and it's beginning to happen. For example, wind energy in some places-- in Mexico, for example-- in some places where there's a lot of wind. So the prices are already beginning to be competitive with fossil fuels. Things are also improving in terms of costs with solar energy. Photovoltaic panels are the ones that are, of course, much more common now, because their prices have gone down very fast. But concentrated solar thermal energy is also something that is beginning to drop quite fast in price. And down to the right, you can see what's happening in Seville. Seville gets it in Spain-- get's electricity that way. And the interesting thing is you can store energy for a while with molten salt. So the first few hours of the night, you can keep using energy that you collected during the day. Because that's one of the worries with these renewable energies, that they are intermittent to some extent.

But even nuclear, okay. This is very controversial. As you know, for example, in Germany, they stopped using nuclear. In Japan, of course, because of Fukushima, they also have a lot of problems with nuclear energy. But in principle, there are some studies, some coming out of here at MIT and so on, that it's a relatively safe way of generating energy, if you do it correctly. Compared to, of course, the earlier versions-- Fukushima, the plants that broke down we're already very old. But the new generation, three or fourth generation, that's certainly a possibility. But anyhow, I leave up, and that's something to be discussed, but it could be an option for society.

But the point to make with all these options, how much would that cost? And here I'm just giving you one example. I think economists-- environmental economists-- are beginning to agree that the cost is not very large, surprisingly. Because one would normally think, wow, fossil fuels are all over, so it must be terribly expensive to limit them. But if you do it right, if you have an international agreement, for example, that puts a price on emissions-- there might be other ways to do it-- and you're creative, if you do it in a way of minimizing otherwise bureaucratic costs, you're talking about 1% or 2% of global GDP. And you'll have to do things, such as do away with some of the subsidies. One example of subsidies, which I've had something to do with, is in Mexico, like in many other developing countries, gasoline and diesel were subsidized. Turns out that 80% of the subsidy was going to rich people, people that didn't really need it. So there are much better ways to subsidize society. At least in Mexico, it has now been removed. But there are many other subtle ways in which this is happening. But here is the point, that 1% or 2% cost, it's a lot of dollars. But it eventually becomes noise.

But the other thing-- I put Nick Stern here again, because I have to work with him relatively closely. But this is representative of other economists-- like Bill Nordhaus-- who initially disagreed, I think are very much more in agreement now. But the point is that Nick Stern recognized that his original report was actually wrong, in terms of estimating not the cost of fixing the problem, but the cost of not fixing it. And so the current views, again, in these economics groups is that the cost is very hard to calculate, but it's much more than they had originally estimated. Certainly Bill Nordaus' estimate was way off initially. Because there are things you cannot even put a dollar value on.

So the bottom line here is that it's clearly much more expensive to deal with the consequences than go fix it, acknowledging that there is some uncertainty. But that's the conclusion. So indeed, it's a myth that it will cost society a lot. It will cost society a lot more if you don't deal with the problem.

And how would this have to be addressed? Well, these are some suggestions, some list of actions, that would need to take place. Putting a price on emissions would be something that would make renewable energies, energy efficiency-- all these measures, some of which I showed before-- it would make them much more attractive. The point is that that would be a way to incorporate what's called externalities into the economy. Costs that society is not paying nowadays for environmental damages. If you begin to include them in the economy, then you would favor reductions in emissions, and again, at the relatively modest cost.

Of course, you have to do a lot more research, and that's one of the places where MIT excels. Many of us think that society is not spending enough in new technologies, or in improving the technologies, so that they cost less. Society could be easily spending two or three times as much as they are doing nowadays, given the size of the challenge. Of course, you need international cooperation so that developing nations are willing to go along.

One very important example here is China. Initially, with the Kyoto Protocol, the posture some years ago was, well, it's countries like the US that's created the problem. So you guys have to solve it. We'll wait until you start, and then we might follow. That's now considered obsolete, and it's certainly the wrong attitude. All countries-- and in Mexico, I'm helping them to play an important role there-- they all have to work together. And, in particular, you can, in developing countries, start with the so-called win-win measures. Measures that are not included in these 1% or 2% costs, but measures that are profitable nowadays, such as using energy more efficiently, or those that have co-benefits. For example, improving air quality. That turned out to be very important in China, because their quality turned out to be a very big problem there. So these are ways in which the problem could be fixed.

But let me go on to what I want to describe as, in more detail, the size of the risk. This is something that the scientific community hasn't done very explicitly yet. But if we look at the IPCC, their last report. What you see in the press normally is the IPCC forecasts, the most likely forecast for the most likely scenario. But here I have a plot of how much would the temperature change for different scenarios. These were carried out with different climate models, sort of averaging them. And the point to make here is, for the decision whether to do something about the problem or not, and how much to do, you don't work with the most likely scenario. You pose the question, what would happen if we continue with business as usual, which is what's happening now? Of course, if we reduce emissions, less things would happen. But if we go on with business as usual, you have here the red portion of this curve, and you can see the average temperature could go up by the end of the century by four degrees. But what is very worrisome is that there is a significant probability, one in five, one in 10, that the temperature will grow about five degrees. That's IPCC.

But this is the best known example, the one I favor most. I was here so many years at MIT, and of course working with Ron Prinn, and so on. These are the greenhouse gamble wheels, which are very famous now. And this is how I explain it, in general, to colleagues and people living in other countries. I don't talk about the wheels of fortune, but I convert this to a roulette, because that's better known in other countries. But here is what happens. Most of you are probably familiar with this. We have now the roulette to the left, the business as usual. And you can talk about the most likely temperatures, certainly well above two degrees. But the point I'm stressing now, similar to the IPCC result, is that there's a red portion of that wheel, which the temperature would grow about five degrees, six degrees or so. So that's a non-negligible probability. One in four, one in five.

So why is that a worry? Well, the economist at Harvard, Martin Weitzman, started with this, but now I believe many more economists and scientists also agree, that in order for society to make a decision how to tackle this problem, you don't look at the most likely event. You look at probabilities that something really unacceptable will take place. And this is the fat-tails of Martin Weitzman. But again, in more quantitative terms, it's what I just showed. So if there is a one in five, or one in 10, probability that the temperature will grow about five degrees, that's extremely worrisome.

Now just to elaborate a little bit, it's not just the temperature itself, but how could the climate change? Well, this is just taken from the literature, so-called the tipping point. Imagine that the position of the little ball there represents the state of the climate. As you increase temperature, you change the shape of the surface where the ball is sitting. And so you increase the temperature little by little, the surface changes shape, but eventually you reach a point where the ball moves a lot. That means the climate would have an abrupt change, which would be nearly irreversible. So because it's a complex system, it's not linear.

Do we worry about these sort of things? Well, there are examples. The Arctic summer ice is already happening, the Amazon rainforest might disappear. And I won't go into the details of thermohaline circulation, but let me be very conservative and go along with the National Academy report. They looked at some of these tipping points. And once you look at them in some detail, perhaps they're not as likely as had been anticipated by some. But their bottom line is what is worrisome.

What we're worried about is surprises, what they call dragons. We don't know. If you change the temperature about five degrees, all sorts of things could happen. So that's a completely unacceptable risk. And just to put it in perspective, I can use several examples. I'll choose one from a colleague of mine, Eric Chivian, here at Harvard, who worries a lot about the effects of climate change on health. But one example is as follows. If you have a baby that is about a month old, or a little less, and he goes to the hospital because he has a fever, and if he has something like 38 degrees Celsius or so, that's worrisome. So what does a physician do? Well, usually, the thing to do is they give him high doses of an antibiotic. That's what is prescribed. But, why? It turns out that only about 10% of the time this fever is due to a bacteria that would respond to the antibiotic. Most of the time, it's a virus. And even if it's a bacteria, well, maybe one out of 10 times or so would the child die. Okay, so there is a relatively small probability that you are giving him the right prescription. Meanwhile, you take blood and analyze it and so on. But that takes a couple of days, and if you are wrong and don't give him the antibiotic, the child dies. So the normal way to think about these issues is-- if I have a probability of one in 10, even one in 100, but I have a very bad outcome-- I just don't want to gamble.

I remember, Kerry Emanuel has another nice example of a little girl trying to cross a street. And she asks an adult, can I cross now? And the adult says, oh sure, there's only a one in 10 probability that you'll get hit by a bus coming. Well, if the adult is responsible, he would walk the girl to the corner and perhaps cross the road. It doesn't cost him very much. So one in 10 is huge. Imagine, with airplanes, if you had a one in 10 probability that they wouldn't make it, you would have thousands of airplanes every day crashing. So that's totally unacceptable.

There is, of course, a complication when talking about a time delay. This would happen towards the end of the century. But things would begin to happen earlier. And if you don't want to worry about the future, and just let society deal with issues that are important at the present, why invest in elementary schools? It's going to take quite a while for that to pay off. So obviously, there are other issues that matter.

Well, I'm quite late, but I'm going to try to finish. Very briefly, I just spent some time at the World Economic Forum at the end of last year, and they did consider risks. But the bulk of the industry considers these climate change risks in the middle of other 30 or 40 risks. Nothing special. Clearly they don't have this quantitative estimate of one in five or one in 10. These are one in a 1,000 or so. So they are not very well informed. Some industries are responding rapidly, but it was only a fraction of the industries represented at the World Economic Forum.

So perhaps I'll show one or two more. What's our worry that we have at present? It's that there's no international agreement. There's a bottleneck. And what's a bottleneck? The US Congress, or rather US Republican Congress. They don't quite believe the sort of things that we are talking about. Imagine carbon dioxide is clearly not a carcinogen, so forget about climate change. So that's our worry, and as a climate scientist, I'm trying to work with economists to try to communicate with these people. If they're rational people, they should be able to respond.

I have a few more, but perhaps I'll just finish with this one, which is a quote from George Shultz. He is a Republican. He was, of course, the Secretary of the Treasury. But he's very much in favor of doing something about climate change. He's very active in California. And we became very good friends after many years. He works here also with MIT, with the MIT Energy Initiative. He was selling it for a while. And you'll see how he quotes the ozone layer problem as an important global problem. And the Montreal Protocol was created during a Republican administration. It can be done. So I'm hopeful, if we bring rationality, we might be able to do it.

And just to finish, the economics are very clear. But talking now, not as an economist, but as a person, the ethical issues are very important as well. We have a responsibility towards future generations. That's not just economics. But we need to leave them, at least with a good likelihood, an environment, where they can have a standard of living at least as good as the one we've had today. Thank you for your attention.

[APPLAUSE]

L. RAFAEL REIF: Questions for Mario Molina? There are a couple microphones on each side of the room.

MARIO J. MOLINA: (LAUGHING) Comments are all right.

AUDIENCE: Thank you for great talk. I have a question about sea level rise. Can you give a little comment on what the latest predictions are on possible sea level rises as a function of the different scenarios, please? Thank you.

MARIO J. MOLINA: I'm not an expert on that, but let me tell you what I remember. First, a little bit of historical perspective. In the fourth IPCC assessment report-- I remember I was at part of that in Norway, in Bergen, with Susan Solomon-- and there we agreed that the IPCC report at that time would not talk much about sea level rise because the literature was just developing. That was interpreted by the press as saying IPCC believes there's going to be no sea level rise. So you don't see the mistake, it shows that it wasn't right. So I think it's one of those issues where you talk about probabilities. It's likely depending on what scenario you have. If it goes five degrees, you would have at least a meter. And perhaps things are happening faster than anticipated. In principle, again, with a probability of one in 10 or whatever, you could have several meters sea level rise at the end of the century with the business as usual scenario that would be catastrophic for many island states. They would disappear. And for large portions of the population even here in the US. In Florida. But again, there's a whole range of projections. It's just certainly one big additional worry, because you can already measure it. You can measure it, and it's not the same all over the planet, but it's already happening.

AUDIENCE: Thank you.

AUDIENCE: [SPANISH], Professor Molina. I had a question regarding an issue of leadership in education I've been struggling with, as someone who worked on renewable energy and energy efficiency. I've started to ask myself whether MIT and its peers can be true educators and leaders, while they still invest their endowments in fossil fuel companies that donate to climate deniers or politicians that negate the science, and how you approach that issue.

MARIO J. MOLINA: Okay, here's what I would think about it. First of all, not all oil industries or energy industries are giving money to the deniers, so you can be very selective. And certainly, being a part of MIT, I know of some of the energy companies that are actually quite actively working, diversifying themselves, and trying to find solutions. If you could separate perhaps some of the real culprits, maybe you could do something about it. I think there are many much more effective actions of society to fight that sort of thing, where they actually, like the Koch brothers, they give a lot of money, as I explained, to these public relations campaigns. So there are much more effective ways of doing that than just conventional divesting of all the oil companies.

Particularly for MIT, if it can work-- this is something we do in Mexico and Latin America as well-- if there are some industries that are polluting, but we sit down with them. First, we explain there are lots of things you can do that are not sacrifices. You can actually reduce emissions and so on. Of course for an oil industry, that's harder. But you have transition fuels, like gas versus coal. You can close down the coal plants, as long as it's a transition point. But it's a longer discussion.

The summary is as follows. I think an institution like MIT should not be in any way be perceived as an advocacy institution, like the Union of Concerned Scientists. I'm a member of that as well. But it should be a very open institution, where people can have different opinions. And so you argue the best you can, with the best science, with probabilities, the way you do it, and so on, but not in terms of self investment, because that has relatively little impact. The same effort could be a lot more powerful if you try to communicate directly with politicians, or things of that sort. But the main problem with that is that, unless you separate-- it would be unfair to sort of try to punish industries that are funding you and actually trying to solve the problem. That, I think, is a very positive way to work. Let's sit down, force it. We know we cannot suddenly stop fossil fuels because that would be far too expensive. But we can do it in a very reasonable way. Let's work together, and so on. So that's perhaps one way to justify it.

AUDIENCE: Thank you for the great talk and focusing on the basics. My question is on the response to global warming. If you had 1% of GDP, and you had to budget it, and make a choice between bringing 10 million people out of poverty or investing in some response to reducing the effects of global warming, do you see an ethical dilemma there?

MARIO J. MOLINA: No. If I understood your question correctly. You could argue, as some have argued, yeah, that's a lot of money and I could use that to bring some people out of poverty. But that's a very poor integrated vision of what's happening. What clearly happens-- I didn't have time to go into that-- is the most vulnerable portion of the population is precisely the very poor peoples who would be a lot harder to bring them out of poverty if you have a three or four degree change, let alone a five degree. That would be a lot more costly. So it would be much more difficult for them to do it. So it is not quite correct that you could use the money better to bring them out of poverty. It would be a lot worse.

So what you have to do, obviously, to solve the poverty problem, but also the climate change problem, just so that it's easier to do it. And there's something you can do that has been analyzed. If there are some very poor populations, and the energy of available to some of them is only fossil fuels, it's okay for those portions of the population to continue using, or to start using, fossil fuels for a while, because it's a small fraction of the total emissions. Until you provide them with enough resources and economic development, so that they get integrated to what the rest of the planet would do. But there's no need to, you could call it, punish very poor people, making life more difficult for them. That, in economic terms, is not at all necessary. But you can train them to, for example, even if they just would, not to have to walk two or three miles everyday just to get food. There might be better ways for them, with solar panels, or who knows-- you have to analyze each case-- where they would have the benefit of the use of energy, or whatever they need, even to have internet, or what have you. So I don't think there's a conflict between poverty and climate change, other than not doing anything about climate change.

AUDIENCE: Yeah, hi, I'll take the unpopular position. Could you speak to Chinese coal, and Chinese growth and Indian growth, and how you propose to reduce Chinese coal growth to the point such that we are-- they're currently bring about four gigatons a year of coal. I mean, they'd have to cut that back to like a 1/4 to make a sustainable cut in greenhouse gases worldwide.

MARIO J. MOLINA: Yeah, that's a tough question. In fact, I was invited-- just by chance, I should be in China now talking to some of the colleagues in government and so on. I can only give you very general guidelines, because that's a whole specialty. How do you drive an economy, and how you deal with these energy issues. The point, however, as I understand it, is that even though China is still perhaps even building coal-fired power plants, it's a lot less than they were doing before, because they want to contribute to the solution of the problem. They cannot do it perhaps as fast as they could or they should. But one of the main reasons, if nothing else, is because people are alarmed by their local air pollution. Much of it comes from coal. So it helps, it's a cost benefit analysis. Fortunately climate and air quality working in the same direction. It was not the case for sulfate particles here in the US in the past. They were opposing each other. But in China, it goes in the same way.

AUDIENCE: It's one thing to say that you can perhaps invent technology that allows India to grow up green and not contribute to the problem. But you're going to have also replace 3/4 or more of China's-- and ours-- infrastructure in order to be able to cut CO2 down to the point it's not accumulating. Their growth, just their growth in a decade, will exceed our entire CO2 emissions.

MARIO J. MOLINA: The hope is that, if it's a whole decade and there's time to develop alternative energy sources, and so forth, that they are already considering other ways to grow. It need not be a drastic solution. Perhaps they are already beginning to bend the curve. I recognize there are some enormous challenges. India has also a lot of opportunities, and it's not very clear they are actually taking advantage of the opportunities not to grow fast just with coal. Hopefully there are alternative ways of doing that, but I don't have sort of a simple answer, you have to do this or that. You have to sit down with them and work with energy economists and so forth. Perhaps the weak point there is politics. Even if you have the best technical solution, or from an administrative point of view, also the best policy solution, you have to work with real government. So how do you that? You just have to sit down, be patient, and talk to them.

L. RAFAEL REIF: We have three more questions, and then we will have to conclude. Go ahead.

AUDIENCE: Professor Molina, you mentioned a number of options, measures to reduce the carbon emissions, and one of them was carbon sequestration. I know about a group of scientists and investors that are proposing to scale to industrial volumes for carbon sequestration, based on some processes of learning corals, to turn them into concrete. The question I have is, is carbon sequestration mature enough to be scaled up to that size?

MARIO J. MOLINA: Well, you have some of the world's experts here at MIT, who have been working for years on that. So they might be able to answer your question very directly. From my perspective, as I understand it, it's clearly something that needs more research. The technology is still expensive, but there is some hope that, perhaps with more research, better technologies and so on, that the price will continue to drop so that it will be a reasonable alternative. That's as far as I understand it. I know it has gone up and down. For a while, years ago, the community was very optimistic that that was going to be a very good solution. And one of the MIT studies, surprisingly, if you want, found that there are enough cavities in the planet, so you could store huge amounts of CO2. So that was perceived to be a problem, but MIT showed that it was not such a big problem. But it's just the technology-- separate the CO2 and so on-- that is at the moment, still, as I understand it, costly. I know there's some research going on. I know the Department of Energy here is investing in that. Norway, and even China, and so on. But as far as I am aware, it's not there yet. So we just have to be patient and keep doing research.

AUDIENCE: Thanks so much for joining us. As a scientist myself, I'm really inspired by your work, which directly resulted in a large scale policy shift with regard to CFCs and ozone depletion. And I see ourselves in the same place now trying to make that transition, with the science of climate change being accepted by scientists. But we're still struggling to adopt a large scale policy shift. And so, I was just curious what you think the best way is that MIT can engage with that process, and really surmount the political barriers towards enacting a price on carbon, increase adoption of renewables, and some of the things that you mentioned today?

MARIO J. MOLINA: Again, it's a tough question. We sometimes compare what we were able to do with the ozone depletion issue with climate change. Of course, climate change is much more complicated, because energy and fossil fuels are such an important component of economic growth. But the sort of things that MIT can do, it's already doing, in terms of research, technology research, also scientific research.

I don't think it would help much doing more advocacy. I think it's preparing excellent professionals. That's one of the best contributions. And using resources from the public, or wherever they come from, to finance the research that is needed.

In terms of policy, you also have some economics and policy experts here. They can contribute. But I think what I would suggest, and it's happening already, is to join forces. We have some groups that are attempting to communicate directly with Congressmen. And so, we think we are beginning to succeed, because it doesn't make sense for them to be so irrational. We tell them, look, maybe you are right. Convince me. We could sit down. What I don't tell them very explicitly is that, if you're right, that means a lot of us are really very dumb. But I'm willing to sit down and listen to you. And that's what I'm suggesting now. To be part of this community that is trying to solve the political problem, but continue to be a very important part of the technology and science contribution.

L. RAFAEL REIF: The last question, please.

AUDIENCE: So in your talk, you mentioned the large difference between the scientific consensus on this issue and the public perception of that consensus. And there is a lot of literature that shows that, simply presenting people with facts that oppose their worldview, may actually do more harm than good. So, in your experiences, what have been the most effective strategies at communicating this issue to both individuals and the press?

MARIO J. MOLINA: That's also a good point. The first comment is that we, as scientists, the scientific community, have done a very poor job of communicating this to the public. You see that with the surveys. Partly because many of us are not trained in that specialty, or many just don't think it's part of their job-- social responsibility. But that's beginning to change. Scientific community is becoming much more aware of the need to do it correctly.

So, as an example, the project that we did, but more importantly, the second phase, we worked with professional communicators. We don't improvise. What do these people do, besides being their academic specialty. You do surveys. You have to experiment, and see what communicates best with the public. So you take a sample of a few hundred or a thousand people, and explain issues that you want to explain in different ways, and sometimes you get surprising results, that, as a scientist, I would not have guessed. But that means communicating effectively. So we need to do that sort of thing at a much larger scale, and we need to engage experts in the scientific community that are willing to spend some time just supporting the science itself as needed for these communication efforts.

L. RAFAEL REIF: Well, thank you. When Professor Molina received the news of the Nobel Prize, the MIT president at the time, the late Chuck Vest, famously said, referring to Professor Molina, "It's great to see that sometimes nice guys finish first." So let's thank this nice guy for a great presentation today.

[APPLAUSE]