What Does Midwest Coal Have to Do with the Price of Shellfish in Seattle? Understanding How Fossil Fuels Contribute to Ocean Acidification

Christopher Sabine

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Thank you. Well, thank you very much. First of all, I'd like to start off by thanking President Ohle and the faculty for this wonderful degree. I'm honored and pleased to receive it. It's quite a humbling thing in recognition of all the past scholars that have received this degree and I, I hope that I'm worthy of it.

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I think one thing that I probably share with those scholars is a real passion for the work that I do. And I guess if there's one thing that I'd like to pass on to the younger generations and students that are here, it would be to find something that you're passionate about. If it's not the oceans, perhaps it's something else. It could be art. It could be history. Whatever it is, find something that you're passionate about and pursue that dream, pursue that direction and you can achieve amazing things.

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The topic I'll be talking about today, I'm extremely passionate about. That is understanding the ocean's role in the global carbon cycle and how the burning of fossil fuels and human activities are impacting our oceans and our marine ecosystems. So I'll talk a little bit about that today.

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If there's one take-home message that I'd like to leave with you, I'll give that right at the beginning. It's a similar message that we got yesterday from some of the talks. Basically that is that regardless of who you are, where you live, all humans on the earth are having a profound impact on the global ocean and the creatures that live there and we need to recognize that and acknowledge that and take actions to, uh, try and preserve what we've got in our marine ecosystems.

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I'll go through three components today in my discussion. First, I'd like to describe the rising atmospheric carbon dioxide concentrations, what's causing that, where the CO2 is going. I'll discuss the impact of that rising CO2 on the oceans and its marine ecosystems. And because I've been told that some of my talks at times can be a bit depressing, I've added a new section on perhaps suggesting some things that we can do to help that so we'll see how that goes.

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Hopefully this is a figure that most of you are at least a little bit familiar with, the fact that CO2 is rising in the atmosphere. The blue dots on the right of this figure show the measurements that we've made over the last several decades. That's shown in the expanded version in the middle of the plot here. But in the big plot, I'm showing CO2 for the last thousand years.

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Concentration is shown on the vertical axis on the left in parts per million. It's very simple. That's just if you were to take a million molecules of air, how many of those would be carbon dioxide. And it would be, in the preindustrial, it would've been around 280 out of those million molecules would be carbon dioxide. And you can see that for a thousand years before the industrial revolution, which was in about 1800, the CO2 concentrations were extremely constant.

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These are measurements made from ice cores where they take a slice of ice and ancient atmosphere is trapped in the bubbles and they can measure the CO2 in the those bubbles. These records actually go back almost a million years now and we see that even going back as far as a million years, the CO2 has never been higher than about 290 parts per million throughout that whole record. And, in fact, we believe that you can go back as far as perhaps 50 million years and not see CO_2 higher than it is today. And yet since the beginning of the industrial revolution, we've been burning fossil fuels and releasing CO_2 into the atmosphere, which has resulted in an exponential growth in atmospheric CO_2. And we know that very well from our direct measurements.

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What's causing that? It's the burning of fossil fuels and other human activities. This is our estimate for 2010. Fossil fuel burning was about nine point one petagrams of carbon per year. Now one thing I find when I'm talking to people is that basically no one has any idea what a petagram is. We heard the talk last night about the iron infintimals 0:07:51.5, just 10 to the minus 15.

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Well, it turns out a petagram is 10 to the 15, so a one with 15 zeros after it. As I talk to people about that, OK, that sounds like a lot of zeros but . . . So, OK, well, let's try something different. How about it's a billion metric tons? OK. Well, maybe that's starting to sound like a lot but still hard to grasp. Kind of like the deficit, you know? It's such a large number.

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So I've come up with an illustration that will hopefully try and illustrate how much CO_2 we're actually putting into the atmosphere. So I ask you to consider a coal train, a box car with coal, which is about 80 percent carbon. That railroad hopper car holds, uh, about 100 US tons of coal that's 80 percent carbon. And that railroad car is about 60 feet long, if you include the couplings. So the question I pose to you is how long do you think a train would have to be to hold just one petagram of carbon?

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It's funny, when I go and talk to students about this, you know, they'll guess maybe 100 miles or some will even guess as long as the country. It turns out, when you go through the math, that that train would be 156,500 miles long. 156,000 miles long. Put that in perspective. The circumference of the earth at the equator is about 24,900 miles. So that means that a railroad train holding just one petagram of carbon would stretch around the earth more than six times.

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We're releasing nine point one petagrams of carbon per year into the atmosphere from burning fossil fuels. You add to that the deforestation. We're cutting down trees at a rate of about 28,000 square miles each year. That's almost the size of the country of Panama that we're cutting down and burning every year. That's adding another point nine petagrams of carbon per year, giving us a total in 2010 of nearly, of about 10 petagrams of carbon per year.

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That means that coal training holding the amount of CO2, the amount of carbon that we've released in 2010 would wrap all the way around the earth 63 times. People say, 'The earth is huge. We can't be affecting it.' But if you think about the numbers, it's a clear gas, we don't really see it. But if you think about the numbers, if you think about just how much CO2 we release from almost everything we do, it really is quite staggering.

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So where does that CO2 go? We burn it in our power plants. We burn it in our cars. It comes out into the atmosphere. Now this is an ocean's conference. You're saying, why am I talking about the atmosphere so much? Well, it turns out that only about half of the CO2 that we release is staying in the atmosphere. Where is the rest going?

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As Jeff mentioned in the introduction, when I first started working on the global carbon cycle, we really didn't know where it was all going. But we think that we've closed that budget now. And our estimates are that approximately half of that remaining carbon is going into the terrestrial biosphere. We all know plants breathe in carbon dioxide and release oxygen, while animals breathe in oxygen and release carbon dioxide.

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Turns out that many plants, particularly trees, grow faster in higher CO2 environments. And that fertilization together with the reforestation of areas that were cut down many years ago is helping to absorb carbon dioxide that's released into the atmosphere now. But the other half of that is going into the oceans. And as an oceanographer, I'll be focusing the rest of my talk on that piece that's going into the oceans because that's what really got me into this is trying to understand why are the oceans taking up CO2? Where is it going and what impact will that have on our global oceans and marine ecosystems?

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Why are the oceans important? It turns out, actually, that the oceans are one of the most important components when you look at CO2 on time scales that we're considering. That is, kind of years to centuries. When you consider on that time scale, there are really four pools of carbon that we need to consider. There's the atmosphere, of course, which is collecting the CO2 that we're releasing. There's the land plants that I mentioned. And below them are the soils. The soils are releasing CO2 into the atmosphere as well. But there's also the oceans. And there's a great deal of natural carbon in these four pools. But of all that carbon, 90 percent is found in the oceans. So ultimately it's the oceans that control in the natural system where all the carbon is going and the state of carbon in the other pools.

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This is just a simple cartoon illustrating the basic carbon cycle in the preindustrial. So this is prior to the human intervention. What we find is that the oceans typically were a source of CO2 to the atmosphere. They're releasing, on a global scale, the oceans are releasing CO2 into the atmosphere. That carbon was the absorbed by the trees. As the leaves fall off those trees and the carbon was regeneralized [sounds like] 0:14:13.3, it went down into the rivers, was transported down into the oceans where it was then released. So we had this giant cycle of carbon in the earth's system of CO2 coming out of the oceans into the trees and then back to the oceans. 0:14:34.2

The atmosphere, as you saw in those ice flow records, was extremely constant in its concentration. If you look at the numbers that I'm showing here, the loss of CO2 from the atmosphere, the exchange, is on the order of 70 petagrams of carbon per year. The only way that the atmosphere could remain that constant is if this whole system is more or less in balance. So we believe very strongly that there was a strong balance, particularly over, since the last ice age, over the last 11,000 years or so between the atmosphere, the oceans, and the terrestrial biosphere.

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And think about it. What's happened over the last 11,000 years? That's the period of which our society developed. We have developed our society based on a constancy of climate. We know that we plant corn in the Midwest in June. Or whenever it is. [laughs] Sorry, I'm from Seattle. We don't plant corn.

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What we've done now is we've, we're modifying that system. So over the last 200 years, we've started tapping into a reserve of carbon that was tied up in the rock record that had we not tapped into it would've stayed there for tens or hundreds of millions of years. This is carbon that was sequestered. It was removed from the system and was not part of those four pools that I discussed that normally exchanged carbon. But because of humans drilling and mining, we're pulling that carbon out of the earth and putting it back into the atmosphere.

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And this is the average for the last decade. You see this number is a bit smaller. Fossil fuel burning, the average for the last decade was seven point seven. I told you in 2010 it was nearly, it was nine petagrams of carbon. So we're continuing to expand our emissions.

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The red areas show the enhanced exchanges of carbon because of human activities. So while we still have this natural carbon cycle, I hear people say, 'But carbon, we couldn't have life on earth without CO2.' That's very true. And carbon is a natural component of our life cycle. The plants couldn't live without it. We couldn't live without it. But on top of this natural cycle, which was in balance for so many years, we've now added this carbon that was sequestered in the rocks and that has basically reversed the role of the oceans in this global carbon cycle.

Where the oceans used to be a source of CO_2 to the atmosphere, now they're a sink for CO_2. They're actually taking up more CO_2 out of the atmosphere than they're absorbing. And that has consequences for how the oceans operate, for the chemistry of the oceans.

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We know this because we can measure it. We've gone out and we've made measurements that actually show this rise in CO_2. The red dots on this figure are the atmospheric measures that were started by Dave Keeling back in the 1950s on the island of Hawaii. And he very carefully made the most precise measurements and showed the steady increase of atmospheric CO_2 in the relatively clean airs around Hawaii. So in the late 1980s, early '90s, we started doing the same sort of measurements in the ocean, saying if we're seeing all this rise of CO_2 in the atmosphere, do we see the same thing happening in the surface ocean?

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And in fact we do. The blue dots show the measurements from the Hawaii ocean time series station. I started these measurements when I was in graduate school in Hawaii and they've continued on since then. And you can see they're much more variable. But in general, the surface ocean is increasing at about the same rate as the atmosphere. And this is basically what we see in most areas around the global ocean. There are few regional differences but on a global average we believe that the surface ocean is increasing at about the same rate as the atmosphere.

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Together with that rise in surface ocean carbon dioxide, we also see a drop in the pH of the oceans. And here's where I have to apologize. I'm a chemist. And I think it's required that whenever a chemist speaks, he must show some equations. So I don't want you to check out. I know a lot of you are groaning, particularly up in the balconies, 'Oh, god, here we go.' I promise only two slides and they're very simple.

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But CO_2, carbon dioxide, is what we call an acid gas. The CO_2 molecules react with the water molecules in the ocean to form carbonic acid. That's why we talk about ocean acidification. As an acid, that molecule releases some of its hydrogen ions. And that's what we're measuring when we're measuring the pH of the ocean is the increase in those hydrogen ions.

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Now those hydrogen ions don't just sit there. They're important because they react with other molecules. And I'm just gonna talk about one and that's the carbonate ion. We find that more than 99 percent of those hydrogen ions that are released react with the carbonate ion to form another compound called bicarbonate.

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Now why do we care about the carbonate ion? That's because a lot of organisms in the ocean produce calcium carbonate shells. Here's my last equation. What we find is that organisms like, think about your corals, your oysters, your mussels, think about the white sand beaches of Hawaii. That's all formed from calcium carbonate. And this is where the organisms take a dissolved calcium ion, they grab a dissolved carbonate ion, they put that together and that makes a solid. They use that to form their shells or their skeletons. And that's calcium carbonate.

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Now we want to look at that and see how that might be changing as we add CO_2 to the oceans. A way to do that that sort of simplifies the way we can look at that is using this index that we call the saturation state, and it's just a relative indicator of how easy or difficult it is for those organisms to produce their shells. OK? It's set up so that any value less than one means that if you were to put that shell into the water, it will begin to dissolve just on its own.

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And the higher that index, the larger that number, the easier it is for those organisms to produce their shells. So let me just show you an example with talking about coral reefs. We're gonna hear a talk later this afternoon by Ove who’s going to tell you about all the different coral reefs and all the different pressures they’re facing. I’m going to focus just on the carbon impacts on this.

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So we can take the measurements we’ve done and the models we’ve run. This is actually a result from a model run by Ken Caldeira. And, uh, we’ve verified this model, confirmed it against some of our measurements. But this is a measure of the index level for that saturation state throughout the global oceans. The scale is shown on the bottom. Again, the higher the number, the easier it is for those organisms to produce their shells. The lower the number, the more difficult.

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On top of this color scheme that I’ve shown here are these magenta dots. The magenta dots are the locations of all the known warm water corals in the world. And this is a figure showing the pre industrial concentration. So prior to about 1800, we can see that basically all of the known coral reefs in the world were growing in these blue waters. These were the waters with very high saturation states; very easy for them to grow. And the histogram on the bottom shows, the histogram here shows where the distribution of all those corals are.

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So you’ll see that all these corals basically are growing in these blue waters. So what we want to do is look at how that might change as we step through time. So this is the preindustrial. Here we were at the turn of the century. So CO2 had increased from 280 to 380 parts per million. You see that the corals haven’t moved but the waters around those corals have changed. There’s a lot less blue in this picture.

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And you see from the histogram that now about half of the corals are in this kind of moderate zone. So the blue is optimal, the oranges and yellows are moderate. They can still grow but not very fast. By the time you get into the reds, the corals basically are stopping, are no longer growing, they’re just existing. And then when you get below one into those pinks and whites, that’s where the corals will just naturally dissolve and dissolve right out from under.

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So what happens as we step forward? Here's where we're gonna be within the next 20 years or so. Almost no blue left. We see that almost all of the corals are in this moderate zone so they're still doing, they're still growing but likely more stressed and difficult for them to continue to sustain themselves.

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What about the end of the century? Estimates for the end of the century range from say 550 to up to possibly as high as 750 parts per million. These are very modest estimates of where we might be by the end of this century. Not that far from now. Some of you up on the bleachers will still be around then. You see that basically there's no blue left anywhere. But the corals will not be dead, but in our estimates, many of them will not be viable to continue to grow and sustain themselves. And when you add that together with what you're gonna hear from Ove this afternoon of all of the other pressures that are facing the corals with the rising temperatures with all the other pressures, scientists are extremely concerned about where we might be in the future with our coral reefs. I'll leave that to Ove to give you that good news.

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That's just one example of the kinds of things that we're looking at. We really started this work with, from a chemical standpoint, of trying to say, all right, we know that carbonate ion is going away and that's gonna make it more difficult for organisms that produce shells to grow. But in fact, as this research has grown, this is really a new field that has been exploding.

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There's been an exponential increase in the number of studies made on ocean acidification and potential impacts over the last 5 years or so. We're seeing all kinds of different things. Not all of them were negative. We see, for example, that photosynthesis generally increases in higher CO2 levels, particularly with nitrogen fixing cyanobacteria. They seemed to grow much faster in higher CO2 environments.

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But it seems the predominance of the impacts that we see generally are negative impacts on marine organisms. Now these are the direct impacts. And there's actually some other surprises, too. We heard the wonderful mercury talk last night. It turns out that a lot of the heavy metals that we worry about in the oceans are very pH dependent, so as you change the pH of the oceans, you change the state of some of those metals. So iron, for example, is a micronutrient that's needed by some plants to help them grow. It turns out that as you lower the pH, you make iron less available for some of those organisms.

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Copper, which is a poison to many organisms, becomes more toxic under low pH environments. So they're impacts that we didn't even think of when we first started doing this work that we still need to try and understand. Things like sound absorption. It turns out that a lot of the compounds, dissolved compounds in the ocean that absorb sound currently are very pH dependent.

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As pH goes down, those compounds change their form and we're anticipating that the oceans will become more noisy. There'll be less absorption of sound. How might that impact our marine mammals and organisms that use marine echolocation and how will that be impacted as we increase our anthropogenic noise from shipping and other sources? So there are all kinds of new areas of study that we're trying to work on.

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Now yesterday I saw there were lots of really cool movies and videos and pictures. As a chemist, it's really hard to do that. So I had to put this in last night. This is my token video of a cool creature that I put in just for you guys. So this is what we call a pteropod. He's a cut little planktonic mollusk. He's a little snail that spends his whole life swimming around the ocean like this. They modified the foot so that they have these wings and they basically fly around. And you can see that he's got a shell around his body.

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And that shell, it turns out, is very susceptible to, uh, to changes in ocean acidification. And they're one of the more vulnerable species that we're looking at. Now you may say, all right, do I really care about a little marine snail that's swimming around in the ocean? But what we're starting to study now and trying to understand is to move beyond just the direct impacts of the CO2 and the ocean acidification on marine organisms and to think about how that may affect things further up the food chain.

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And this is just, again, one example. With the pink salmon, there was a study done in the, there have been studies done for a number of years in the Gulf of Alaska, up in the area where I'm from, looking at why do we have more or fewer salmon recruitment, salmon growing up to be adults that we can catch from one year to the next? And there've been millions of dollars spent on trying to understand the impact of changing temperatures on these salmon.

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But some studies were done a few years ago looking at the diet of the juvenile pink salmon, again, just as one example, and they found that almost half their diet was made up of these pteropods, these organisms that we think are going to be put in jeopardy with ocean acidification and may no longer be around. And what they found was that while a 10 percent increase in the water temperature leads to a 3 percent drop in the mature body weight of a salmon, this is what they've been studying for years. But a 10 percent decrease in the pteropod production actually leads to a 20 percent drop in the mature salmon body weight.

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This is a new area of study, a new impact that we didn't even consider a few years ago that we're now trying to understand, what might these cascading affects be? You know, we may not care about pteropods. I don't know about here in Minnesota, but in Seattle, we really care about salmon. [laughs] And so this has become a big issue for us.

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So as we start to study these different impacts, we need to try and better understand what's going on. And I will say that this is still a very new area of concern where there's a lot of new research coming out. We're finding out new things all the time. Again, there are pluses and minuses. There are winners and there are losers. But we feel, those of us scientists that are studying this field, that there is enough evidence to suggest that this could be a problem, that we need to take action now.

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So where do we go from here? As mentioned, I've been a part of the Intergovernmental Panel on Climate Change. This is an organization that pulls together thousands of climate scientist every year to do an assessment of the current state of the planet and our understanding of the science backing up that state of the science.

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But I think it's really fascinating, one of the things that the IPCC does is to look into the future and think about how things might change in the future and they develop these things called scenarios. And so early on in the IPCC process, back in 1990, there was a group that put together these scenarios and said, all right, how do we think CO2 emissions might change in the future?

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They said, for the next 10 years, we don't see things change really very much. So we'll just assume that things will continue as they have for the next 10 years until let's say the turn of the century. But by the year 2000, surely there'll be all kinds of new technologies out there and improvements that we can make and they came up a range of scenarios that involve future emissions, future technologies that would allow us to become more efficient and have alternative fuels so that we're less reliant on fossil fuels. And they projected and tied up in here is the growth of the human population, our energy needs. So they put together these different scenarios for how CO2 emissions might change in the future.

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And I think it's really fascinating that there were a lot of arguments at the time that this came out. You see that most of these estimates are on the order of 1 to 2 percent growth in CO_2 emissions. There was one that received a lot of criticism, this A1F1 scenario, that had a 2.4 percent increase in our growth of CO_2 emissions. It's this red line up here. One of the higher ones that people were saying, 'There's no way that we will go over a 2 percent emissions globally.' So these are all global numbers. So I find it really fascinating now, 20 years later, to go back and say, well, so let's see. These were their estimates back in 1990. How are we doing?

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So these are our actual emissions, global emissions of CO_2 over the last, between 2000 and 2008. And what you see is – or between 1990 and 2008 – and what you see is that between 2000 and 2008, our CO_2 growth rate has been about 3.4 percent per year.

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Now I stopped this plot in 2008. Anyone know what happened late in 2008 and 2009? It's when we had our global recession. We put on the 2009 number, we actually saw a drop in the global CO_2 emissions. We can make a difference. Now I'm not saying the recession is good but the point is, people say, 'Oh, well, we can't change that.' You know, 'It is what it is.' But, in fact, we can. We don't need a recession to do it. We just need to make a decision to make a difference.

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Now that was 2009 and there were, there were a number of scientists in the IPCC that looked at that and said, 'OK, we've had this kind of step decrease in our CO_2 emissions. What's going to happen in the future?' And they were projecting that, all right, we'll just continue on that same path but with this kind of offset from that one year once the economy gets going again.

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So that was 2009. If we add in our 2010 number, we had the largest single-year growth in CO_2 emissions over this whole period. And we're basically right back up on that red line. And it looks like 2011 is going to be very similar to that. So what does that mean? Getting back to the oceans, I guess another point that I would like to make is that it's not just the magnitude, the amount of carbon that we're adding to the atmosphere, it's the rate that we're adding it that makes a difference.

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This is a plot from Ove, he'll be speaking this afternoon, but he was pointing out that if you look back over the last half million years or so, the rate of change of atmospheric CO2 was less than one part per million per century. Over the last 200 years, we've increased CO2 from 280 to today it's about 392 parts per million.

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Over the last 100 years, the rate of increase of carbon dioxide in the atmosphere is about 50 times higher than anything we've seen in the geological past. And our projections for the future over the next 100 years range from 150 to perhaps as high as 400 times the rate of change that we've seen in the past. So, yes, CO2 has been higher in the past. CO2 was higher during the time of the dinosaurs, during the Jurassic period. But think about, what was the environment like during the time of the dinosaurs? Was it the same environment we have today?

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Even on top of that, it's this rate of change that's important. So I guess my second point that I'd like to make in addition to the fact that all of us are contributing to this effort, is that even if we can't completely stop burning fossil fuels immediately, which I realize is an extremely difficult problem, if we can at least slow it down and give our marine ecosystems and our earth an opportunity to adapt to the changes that it's experiences, at least we're giving the earth a chance.

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Let me tell you one more story, with the premise of if we can slow things down, we can at least begin to think about and consider possible adaptations and alternative approaches for the future.

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Again, I'm from the Seattle, from the Pacific Northwest. Oysters are a big industry where I come from. These are the oysters that we've got in our area in Washington State. Commercial oyster hatcheries are about $100,000,000 a year industry, about 3,000 jobs. Yet for the last 7 years, there's been essentially zero recruitment of new baby oysters into the wild natural estuaries in the Pacific Northwest. This, of course, had a number of the people alarmed. It's actually a scenario that's happening all around. The Chesapeake Bay oyster industry has already collapsed. We're seeing this all around the country and all around the world.

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Where are the oysters going? One thing that the oyster hatcheries figured out pretty early is that it seems to be associated with upwelling. This is a term that you heard a couple times yesterday. I thought I'd just quickly explain what that is. On the West Coast of the United States, in the summer, we typically get winds that come from the north and blow right along the coast. What that does is that pushes water offshore, that surface water, it moves it off the coast. And that water then gets replaced from below. So it's called upwelling. It's where the water is physically dragged up to the surface from below to replace the water that's moving offshore. And that water from below typically has very high natural CO_2, low pH and low oxygen, and that has real consequences for the marine ecosystems that live there.

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So one of the things we did back in 2007 when we realized that there really were very little data looking at the carbon system along the upwelling coast of the west side of North America. We put together a cruise and went out on a ship and made some measurements. And I'm going to show you just some example data from this line five, right on the California/Oregon border, where we went out in June and we saw the strong upwelling.

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So you see offshore here, you have a typical temperature structure where it's warm in the surface and cold down deep. But as you move onto shore with these winds and the upwelling that's occurring, you see that cold water is being dragged up onto the continental shelf, which is shown here in the gray area. So that's what upwelling is. It brings that cold, deeper water from, you know, 150, 200 meters, up onto the shelf.

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This is the temperature structure. And here's that saturation index. So this is that ratio that I showed you where I said if the values get below one, which are shown in the blue and purple colors here, that means that calcium carbonate shells, the shells of those oysters, clams, mussels, will just naturally begin to dissolve if they're exposed to these waters. We're seeing these waters being brought right up onto the shelf and all the way to the surface. And this is the pH. If we look at the pH, these are very corrosive, low pH waters that are being brought up onto the shelf.

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As we surveyed the whole shelf, we can see on the left you see the, the surface aragonite saturation concentrations. Again, with the blue values indicating the areas where we see undersaturated of these corrosive waters, all the way right up at the surface. But if you look down at the bottom, so right along the continental shelf, right along the bottom waters, basically we saw these corrosive waters everywhere along the west coast of the United States.

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This was not predicted a few years ago. The global models that we were running were saying that we wouldn't see these corrosovie waters at the surface for another 50 years. But, in fact, that physical mechanism of the upwelling bringing those deeper waters up until the shallows and up into our estuaries is bringing those corrosive waters right up onto the shelf even today.

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And our estimates are that figuring out the manmade component of that, that in the preindustrial, although there was upwelling in the 1800s, the CO_2 concentrations were lower and those waters were not corrosive, not as corrosive as they are today, and certainly not below this critical level of one.

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So what we did was, we started working with the shellfish industry saying, OK, we see that this upwelling is bringing these corrosive waters up. Could that be what's causing some of the problems with the oysters? And what they found was from tank studies, looking at the oyster larvae, what they found was the oysters spawn, so they release their eggs out into the wild and they drift around for a while. And that's how the oysters spread out. At some point, those larvae start to form their shell. And that shell is what makes them heavy so that they settle out and then if they happen to settle into an area where they can attach and grow, then they're happy as clams.

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What we found from some of the tank studies was, under elevated CO2 conditions, they just can never generate that initial shell, and so they never settle out. So they just end up floating around until they die. And we think that's what happening. So what we did was, we put some sensors into these hatcheries. And this is work that we've done with our colleagues at the University of Washington and Oregon State University and in partnership, close partnership with some of the shellfish hatcheries like Taylor Shellfish and others.

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But what they saw was when you have winds from the south, so remember I said it was the north winds that cause the upwelling, when you have winds from the south, you don't have the upwelling. We see lower salinity because that means that there's more local water from the estuaries, which have rivers flowing into them, so that's just an indicator. That's when they were getting a good survival of the larvae. And we see these very high saturation states. So when you have winds from the south, when you don't have the upwelling, the oysters are very happy.

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When you do have the winds from the north, so here we're seeing the winds from the north, these upwelling-favorable winds, we see higher salinity, that's indicative of more water coming in, this deeper, colder, higher-salinity water coming from offshore into the estuaries, that's when all the larvae are dying. So that showed us, and showed the shellfish growers that, in fact, chemistry does matter. It's not just biology. Sorry, I- I'm not sensitive about that. [laughs]

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Working with the shellfish industry, we were able to make some suggestions on how they might change some of their protocols. Another thing they did was, they were flushing their tanks with water from the estuary once a day. They would come in in the morning and flush their tanks first thing in the morning when they got to work. That's absolutely the worst time to do it. At night, you've got respiration. You've got all the animals and the plants breathing out carbon dioxide. The highest concentrations of CO_2 we see in the water are first thing in the morning. If you're gonna flush your tanks once a day, do it in the evening, after you've had all day of sunlight for the plants to grow and absorb that CO_2, where you'd have the lowest CO_2 concentrations.

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So making some of these simple changes in their protocols, by their estimates, the estimate of the shellfish industry in the Pacific Northwest, they're estimating that we saved them about 35 million dollars a year by just changing some of their procedures based on what we've learned about the chemistry of CO_2 in these waters.

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Now the problem is, this is a short-term fix. We can tell them – we can help them to correct some of the things that they're doing now, but ultimately this is a global problem. We're seeing the CO_2 increase everywhere in the world. And sooner or later we're going to have these high CO_2 values everywhere.

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So what can we do? There are a number of different approaches that we need to take. The first of which, and the main one that I'll just focus on today, is conserving our resources. Even without thinking about changing technologies, it is estimated that we can save as much as half of our CO_2 emissions just by changing our practices and conserving our resources so that we don't burn as many fossil fuels.

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This is just for the U.S. Our fossil fuel emissions between 1973 and 2010, you see that we've seen a dramatic increase in our emissions from transportation. Transportation actually accounts for about 28 percent of our total emissions on a national level in the United States. And think about, the average car in the United States now, average automobile owned by an individual, gets about 17 miles per gallon. If we can improve the fuel efficiency of those cars by 10 miles per gallon, just one car, improve fuel efficiency by 10 miles per gallon, so from 17 to 27 miles per gallon, if you drive 10,000 miles a year, you can save 4400 pounds of carbon dioxide that you're releasing into the atmosphere. We have cars now that can get, 40, 50 miles per gallon.

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Another thing we can do is to think about our electric, our electricity use. These others, the residential, the commercial, and the industrial, represent mostly, most of those emissions are from generating electricity to run those businesses or to run our homes. 41 percent of the total emissions of CO_2 in our country come from electric power generation. There are alternative ways of generating that power and most power companies now offer green power opportunities. You know, is it worth paying a few extra cents per kilowatt to help save the planet? I think so. And I think Ove will talk a little bit more about the potential for moving from a fossil fuel-based economy to some alternative approaches.

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It's not just the United States. It's been noted that our emissions in the United States actually have been dropping a little bit. You can see that here. Actually we've seen a dramatic drop over the last couple of years, again, associated with the recession, in our transportation emissions. We've also seen a nice leveling off of some of our electrical emissions. That's been primarily a combination of conservation and switching from coal to more natural gas which is a lower CO_2 per kilowatt. But we're still a bit part of the problem. China passed us a few years ago in total emissions but we're still way up there. There's a lot more that we can do.

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I’m sorry to say, Ove, that Australia actually passed us very recently in the per capita emissions, so we’re no longer the best, or the worst, whatever the case may be. But still there’s much more that we can do. But we also need to encourage other countries to, we need to set an example, I think, in reducing our CO2 emissions.

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So let me just close up, again, I had put a few pictures of pretty things on here. Coming back to the oceans and say that I’m not suggesting at all that we’re going to kill everything in the oceans. OK? Don’t read too much into what I’m saying. We have real concerns over how the ecosystems will change. There’ll be winners and there’ll be losers. But think about our oceans today, this amazingly diverse array of organisms from the smallest bacteria up to the largest predators. You know, even things like polar bears that are an active part of our marine ecosystems and are potentially endangered from the activities that we’re making.

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I’m not saying at all that we’re going to kill everything in the earth. But we are going to change our marine ecosystems. They are changing already. You’ll hear some of that this afternoon. The real question is, are we as a society willing to accept the changes that we are forcing upon the oceans and upon our marine ecosystems?

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So I’ll just leave it there and, again, the speakers yesterday all had a cartoon, so I had to put in a cartoon here. Thank you very much.