Audio file

119001-ClimateChangeByVincentGimbert.mp3

Transcript

So as I explained, this lecture is on climate change. And what I will aim to cover today are the following points. So I want to discuss a brief overview of the state of the Earth climate today. And we'll look at different time scales. As you know in physics, we like to try to understand principles, fundamental principles that are time independent. And then I'll give a brief history of climate science. So just so you get a sort of historical perspective. as to when this science started to emerge and for how long humanity has been really interested to applying the laws of physics to the understanding of the Earth's climate. Through that, we'll discuss some of the causes and consequences of climate change. And again, we'll look at different time scales to better appreciate what has been happening for the last few decades. Maybe we could even argue a couple of centuries at most. And then finally, a few words on how society may attempt to address the issue. There are obviously very many ways in which this could be addressed. It implies not just science, but politics, economics, and all sorts of other social sciences. So it's a complex issue. But at the root of this issue is a scientific issue. So there's got to be some sort of scientific consensus beforehand. And we are going to try to review those in the first part of this lecture. So first of all, we aim to define what climate actually is, what we mean by that. And in a very simplistic way, climate can be understood as being the average weather. So it's a description of the state of the Earth's atmosphere in terms of its evolution over relatively long time scales. So the weather typically is interested in what's happening in the next few days or maybe the next few weeks. perhaps try to do seasonality predictions, but climate is looking at longer time scales. So from the scale of several years to several decades and possibly several centuries and even several millennia. So climate science looks at the long-term averages to try to smooth out the very short-term effects that are due to what we typically call the weather. The weather forecast is limited, and so even if we are to try to run the current forecast models that we call deterministic weather forecast models, we would not be able to make predictions in the very long term, because the equations of weather forecasting are very complex and stochastic in some way, so a lot of noise, a lot of propagation of random noise through complex differential equations, so it's very difficult to actually deterministically predict it. But the purpose of climate science is to try to get an idea of the major physical effects that are driving the system to understand it in the long term. So what we know from a lot of records, and we go through that, is that climate has always changed. There are many natural phenomena that explain how climate changes over time, over long time periods. And we first need to be able to have models that can reconstruct past climate as measured to be able to validate our understanding of what really drives the climate, what are the main parameters that we need in our models to accurately be able to make predictions. Because ultimately, you want to understand the past and get your physics correct, calibrate your experiments so that you can make useful predictions and have a sense of the uncertainties associated with them. And what we are interested in particular in this context is the change in climate in the sort of post-industrial era, which effectively means for the last couple of centuries, and then more specifically over the last century and as it happens nowadays. So this is perhaps the post-industrial climate change that most people talk about, because this is what concerns us immediately. But I want to give some overview of how the climate has been changing over a longer time scale. So we need to understand a lot of data points. And perhaps the most obvious and simplest data set that we can try to discuss for the last couple of centuries, you can see 1800 on the left side of the x-axis and nowadays on the right-hand side. the temperature anomalies or temperature differences or temperature change over the last century by various methods, even proxies, that means indirect methods, or direct methods, so simple basic thermometer measurements spread out across the globe. We actually have quite a good array of thermometers, and that's been going on for a long time, because the recording of climate has been of interest for many, many different types of applications, including industry, shipping, understanding what's going on and predicting the weather in many, many situations. And what we see is that there's been, roughly speaking, about a one degree temperature increase at the bottom of the atmosphere between about 1800 and today. And that appears to accelerate, especially in the last sort of 50 years or so. And this is the thing we try to understand. What is that? Is this natural variability? And if not, what might be the cause of that? But you can also look at other types of records. And the IPCC, which is the international organization that tries to compile any type of research on climate and produces a report every few years, looks at all sorts of trends over time. And what you see here, for instance, is global average temperatures at the surface in the top panel, but you could also see global average sea level. So we now have very precise ways to measure sea level from satellites. You can look at snow cover and you can look at any atmospheric parameter at the bottom of the atmosphere, at different layers in the atmosphere as well as from the top of the atmosphere. You can do radiative experiments. There's all sorts of ways in which you can look at the climate. And we try to put all those trends in context and try to make sense of them. That's the idea. And so what we observe, almost regardless of which metric we're looking at, is that there appears to be a warming across the globe. And it's not just happening on a worldwide scale, but it's also happening at a regional scale. So we seem to be observing the same trends everywhere, across land and across the sea. So you can see the global changes. the land changes and the ocean changes. And what we see is that it's actually increasing more over land. And we can look at the past 1,000 years. And when we do that, what do we see? We see that actually climate has changed more or less, has been quite constant, but it has actually gone up quite a lot over the last 100 years. So there seems to be really some sort of of a trend that is new. And you can actually look at tree rings, interestingly enough, because tree rings effectively are a record of climate. They can tell you what the climate was like in the past. So that's what you can look at to go back 100 years, maybe a few 100 years. But you can also go back a few thousand years by drilling ice into, drilling ice core into a big glacier. And the deeper you go into the ice, the deeper you go in time. So when you look at this graph, on the left-hand side, you see 800,000 years. So today here, it's zero. It corresponds to today's climate. And 100 corresponds to 100,000 years, and that's 800,000 years. So if you look at this trend here, there appears to be some sort of cycle. And the amplitude of this cycle is actually quite large. So you can see the temperature difference or temperature anomaly. goes from sort of minus 10 to plus 5. So there's like a plus or minus 5 up to even 10 degree amplitude in this type of signal, which is a bit complex because it's not a very, very, very periodic signal. It's like a quasi-periodic signal. And the reason for this is because there are actually different phenomena taking place at different time scales to explain this variability. So you have the superimposition of different sinusoidal waves, if you wish, with different time scales, the result is a complex system. And if we look in the very long time scale, what we observe today in terms of the difference is not so large. We observe a difference of 1 degree, but what we'll see is that we predict differences of the order of several degrees, two, three, maybe 4 degrees. So what we predict to happen potentially, and we'll go back to that in terms of the next century, might be of the same order of magnitude that what has been occurring over time scales of typically 10,000 to 100,000 years. So there's a clear time scale issue here. But what's very interesting is that if you look at the ice cores, you have a good idea of the main parameters driving the climate at long time scales. And of course, understanding what the climate does naturally is crucial. What you see actually here on this ice core is actually a layer of dust. There has been deposited volcano eruption. So you can sometimes also use those ice cores to date specific events, like a massive volcano eruption that actually spreads dust all over the globe and actually covers the whole ice, perhaps in Antarctica or in the Arctic. This is the epica ice core in Antarctica. with dust. And this might actually literally give you a signal in the ice core, because for maybe a year or several years, the ice was completely covered in snow. So you can really go back in time by going deep and diving and digging deep into glaciers. There's a whole area of glaciology that actually is trying to achieve this very purpose. So it's very fascinating in many ways. This is what an ice core lab or repository looks like. So there's archival of thousands of ice cores corresponding to different depths, and every depth corresponds to a different time period. And you can retrieve those, and you can try to measure many things. And one of the things you can measure is the concentration of different gases into the air bubbles that have been trapped inside the ice core. So as you know, ice cores are created because snow falls, and then snow gets packed. And as it gets packed, some air bubbles are trapped. And they are being kept just a bit like in a freezer, really. And so if you can take a slice of ice for a given time period and you melt it and you retrieve the air that comes out, you can estimate, you can look at the atmospheric composition in the past. So one of the things that scientists do is they look at oxygen concentration, CO2 concentration back in the days. And they can even look at isotopic ratios of oxygen to try to figure out, to retrieve as a proxy, the temperatures that would have been present in the atmosphere at the time when those bubbles actually formed. So we really have a very good way to go back in time and do those measurements. So that is for effectively our long-term understanding of climate variability. But climate science, really the science itself, so how it developed, mostly started in the 19th century. So we can say about 200 years ago. And of course, this was the beginning of development of physics and applied physics and the crossover between different scientific disciplines, where you started to have geologists and physicists and mathematicians and chemists and biologists starting to work together to address complex problems. such as understanding what drives the climate. So dates back from about the 19th century, and we'll go through a couple of historical figures that have been really key in our understanding of climate science. What has now been effectively understood since then is that the atmosphere of the Earth, the thin layer of air between the Earth itself and the rest of outside space, is one of the key factors that actually drives climate. It drives the weather, obviously, but it also drives the climate. And so a great deal of understanding was obtained by studying the relationship between radiation from the sun, radiation from the earth, and the composition of the atmosphere. Now the composition of the atmosphere is kind of stable in terms of its mass because it's mostly oxygen and nitrogen, but you have gases that actually have a low concentration in the atmosphere, but actually play a big role. So what matters in terms of the effect of different molecules on the climate is not just their mass or their relative quantity, but it really is about how radiatively active they are. And so the Earth really was proven to play a big role in this system. And Joseph Fourier was perhaps one of the very first scientists to really have the intuition that perhaps the Earth's atmosphere was effectively acting as a greenhouse. So as you know, the name greenhouse effect is the effect that explains the importance of the atmosphere in terms of trapping infrared radiation. And Joseph Fourier, who is well known and more known as a mathematician, you must have heard about Fourier analysis, Fourier transfer, or you have or you will. Fourier was also a politician, but also a great, we could say, naturalist, because he was very interested in making sense of science and wanting to understand the climate. So he proposed in 1824, he wrote this, the temperature of the Earth can be augmented by the interposition of the atmosphere, because heat in the state of light finds less resistance in penetrating the air than repassing into the air when converted into non-luminous heat. So that sounds like quite a complicated sentence, partly because the vocabulary that was used back then is different from this more scientific vocabulary that we use today. But effectively, what he's saying is that the fact that the atmosphere somehow comes in between the arrival of solar radiation and the escape of infrared radiation from the sun has a profound impact. on our climate. That is really the idea. And so he based his idea on experiments that he did with a quite famous Swiss geologist called Horace Benedict de Saussure, who also was very interested in understanding the climate, but from the point of view of geology. So he was very interested in climbing in particular. They wanted to know, people wanted to climb also because they wanted to know the state of the atmosphere at higher altitudes. Obviously, Physical mountains give you a very good way to access very higher, much higher altitudes. So if you don't have planes and drones and satellites and balloons and everything, then you've got to do what you can do. And so there was a generation of geologists and meteorologists and climate scientists or the early climate scientists who are very keen to climb the highest mountains to be able to make some sense of the state of the atmosphere at those altitudes. And in Europe, the highest mountain is Mont Blanc at nearly 5,000 meters. And so obviously we know the pressure and the temperature is very different. Humidity is different as well. And so people wanted to understand really what was going on at different heights in the atmosphere to make more sense of that system. So this is a representation of some of the epic journeys that Saussure and some of his scientist friends made to climb to the top of Mont Blanc, so 4,810 meters at the border between France, Italy, and not too far from Switzerland as well. You can see Mont Blanc very well from France, but also on the other side from Italy. There's a large tunnel actually below Mont Blanc that connects France and Italy, a beautiful region. And nowadays people climb Mont Blanc relatively easily. But you have to imagine seeing the type of clothes they were wearing, that climbing Mont Blanc back in the days was a real, real adventure. It is still today, by the way. But those scientists in about 200 years ago climbed Montblanc. And Saussure was one of the very first to get to the top. And he obviously did not forget his instruments to be making scientific measurements as soon as he got to the top and all the way up, because he was very, very keen to understand what the atmosphere was telling him at those altitudes. And if you go on the French side of Mont Blanc, you will see actually a couple of statues of Horace Benedict de Saussure, as well as Dr. Balma, who were the first to climb Mont Blanc and make those measurements. So Fourier and Saussure were pretty much the first ones together to suspect the presence of the greenhouse effect as an important factor in the understanding of the climate. So we only pick a few dates and a few scientists, but obviously it was a continuous process. John Tyndall, a few decades after, made very important measurements. And in 1859, he made an experimental discovery of what we now call the absorption of thermal radiation by the atmosphere. And so he actually made measurements in London at the Royal Institution, and he set up an experiment that showed that the atmosphere or the different gases in the air were responsible for the absorption of a lot of radiation that comes as a result of emission by the ground itself. So the Earth, you as a body, this room, and the Earth emits radiation just like the sun does, but at different wavelengths and in different quantities. And this is called infrared radiation because the wavelength of light that is emitted is not visible, is longer than red light, And therefore, we call it infrared. It corresponds to emission of light from objects that are colder than the sun. And the radiation is telling you something about the temperature of the object that actually radiates. But what he was interested in is to see how that radiation was absorbed by the air. So he set up those experiments, and he came up to this conclusion that there were gases in the atmosphere that were responsible for an attenuation, a reduction, in the propagation of infrared radiation. So therefore, he postulated this idea. And in fact, he proved that the atmosphere can absorb infrared radiation. And so as we know, that infrared radiation is one way in which the Earth can cool to space. If you have a layer of air above it, and you absorb this heat, you retain some of the energy into the system. And therefore, you expect a warming as a result. So he made really some groundbreaking measurements of different types of gases, different types of molecules, and really was instrumental in understanding the spectroscopy of atmospheric molecules and their relationship to the Earth's climate. And then Svante Arrhenius, who also got the Nobel Prize in Chemistry, who's quite famous in the world of chemistry because you all know about Arrhenius equations. But he was also interested in climate science and in physics as well. And towards the end of the 19th century, he really not only just identified, but calculated the influence of carbonic acid, so now what we most typically call carbon dioxide, CO_2, upon the temperature on the ground in the Earth's atmosphere. And what he actually calculated with very, very complex and long handmade calculations is that he measured what we call now the sensitivity of climate to CO_2. And then the CO_2 climate sensitivity is a measure of how much you expect the Earth atmosphere to warm up by as a response to a doubling of CO_2. So you run a thought experiment, you say, if I were to double the amount of CO_2 in the atmosphere, what would be the temperature response of the system? And he measured that the temperature response would be of the order of 5 degrees for doubling of CO_2 concentration. And it turns out that the current models prove that the increase in temperature as a result of that is very, very close to what Arrhenius actually calculated back then. So I think what it goes to show is that the physics of the warming of the system as a result of the increase in CO_2 concentration is something that actually is relying on really quite basic fundamental principles of physics that were understood over a century ago. So it really isn't a new science at all. This animation here is a simple animation that shows that, as I discussed, the sun provides energy in the form of light, of visible electromagnetic radiation to the Earth. The Earth reflects some of it, but obviously absorbs about 70% of that. So obviously, that has a result of warming up the Earth. But if there wasn't any cooling mechanism for the Earth, then the Earth would warm up forever. And then the temperature could potentially go to infinity. And obviously, it's not what we observe. Because as the Earth warms up, it also emits radiation, just like the sun does, but at a different temperature. And so the Earth, as a system, has adjusted its temperature to the point where what it emits, and you can see those red arrows in the form of infrared radiation, is on average equal to what it receives. So it reaches a point of radiative equilibrium, and that radiative equilibrium is what actually explains the average equilibrium temperature of the Earth, which is about 15 degrees Celsius on average, on average across seasons and across different regions of the globe. So it's a very simple energy balance. And in fact, the physics students will be doing calculations to actually estimate, calculate the temperature of the Earth just as a result of this very simple radiative balance. So what our scientists have proven is that in the 19th century and the 20th century is that the greenhouse effect is important. There are some gases in the atmosphere that are responsible for the trapping of infrared radiation. And as a result of that, modify the state of the Earth atmosphere and the state of the climate. And so you might ask, so OK, so what are the most important gases that absorb infrared radiation? So this is really a spectroscopy question that Tyndall was trying to answer. And it turns out that among the various gases present in the atmosphere, Water vapor is the most active gas. So water molecules in the form of gas, they also exist in the form of liquid droplets, in the form of clouds, but their interaction is different when they coalesce into liquid droplets. But when they exist in the form of water vapor, so just as a gas in the atmosphere, the humidity in the atmosphere absorbs infrared radiation and can re-emit it. at a different temperature, at the temperature where it is located into the atmosphere. And so effectively, the greenhouse effect is a natural effect, because most of the natural effect is driven by the presence of water vapor. And if you look at the spectroscopy of water vapor, it actually has many, many lines, because it's a complex molecule. It has different modes of vibration and different modes of rotation. And if you study... the quantum structure of the water molecule and the different modes of vibration that it has. It has many, many lines in the spectrum, and it even has parts where it has a continuum of absorption. So effectively, water vapor absorbs across the whole infrared range, and therefore is the most important and the dominant greenhouse gas in our atmosphere. So what's important to know is that the greenhouse effect is a natural effect, and without it, there would not be life as we know it, because the natural greenhouse effect increases the temperature of the Earth by somewhere around 20 to 30 degrees. So if you remember that the average temperature on the Earth is about 15, plus 15, without the greenhouse effect, without the natural greenhouse effect, the average temperature would be below 0 degrees. And so we wouldn't know water in liquid form, and you can imagine the consequences it would have for life. So the Earth, as we know it, really works because the natural greenhouse effect, mostly driven by water vapor and sort of natural levels of CO_2, is present. So what we're looking at when we talk about the greenhouse effect, effectively, most of the time we're looking at the change in the greenhouse effect and how additional amounts of CO_2 into the atmosphere can amplify the already existing greenhouse effect and can then, as a result, change the climate. So what we sometimes call anthropogenic greenhouse gases are the ones that are particularly important. If you measure those, and I've spoken to some of our students about this because we have got CO_2 measurements in many rooms across UCL as a proxy for the air ventilation in the room. CO_2 can vary quite a bit, whether you're in a room outside, whether there are people or no one in the room. But if you measure that far away from a source of CO_2, you can try to get an idea of the sort of average CO_2 concentration for the Earth. And over the last 60 years or so, we see an increase from about 300 PPM. So PPM stands for parts per million. So 300 PPM means 0.03%. So it's 300 per million. So it's It's basically a very small amount. It's 0.3 particles per thousand, so 0.03 per 100. So 0.03% in terms of particle number in the atmosphere. And it has risen to over 400 PPM today. So you see the effect that it has, if ever it's not a question of mass of this gas, but really the fact that it is active in the infrared range where it really matters for the greenhouse effect. So we monitor that very closely. There's an interesting annual cycle, but even if you smooth it out, you see that currently we are on a trend where CO_2 has been going up very steadily. And in fact, if you zoom out, it almost looks a bit like an exponential at the moment, although it is kind of slowing down at the moment, or starting to slow down. And if you look at longer time scales, so now we're looking at about 2,000 years, so we have to rely on more proxies. to be able to assess that. What we observe is that CO_2 was around 250, 280 ppm, more or less for the last 2000 years, and really started to shoot off. And now we are talking about over 400. Today we are probably around 420 ppm now. It's a few ppm added every year. But if you look at other gases as well, like methane or nitrous oxide, sometimes called NO_x, you can see a similar trend. And so what it shows is that you have other types of pollutions. that are co-emitted with CO_2. So although they may not have an effect on the climate itself, they give you an idea about the source of the additional CO_2 because you have other gases that are increasing at the same time. And so if you know that some gases tend to be co-emitted, then you can have a better understanding about where those gases are coming from. Nowadays, we are at a point where some people are able, by making measurements, to actually trace the actual source of CO_2 by just making CO_2 concentration measurements. combining that with very complex models. You can even retrieve from actual atmospheric measurements, almost in real time, the locations from which the CO_2 has been emitted. And so obviously different countries emit different amounts. And so that's of interest as well for what concerns us today. So we need to predict future climate change. Now we understand some of the components of that. And so we need to run basically large computer models, feed those models with adequate data, with good physics that is validated with past measurements, run those models and make predictions for what we expect. So we simulate the effect of CO_2. We run models, we try to validate those models, we cross-calibrate the models with respect to each other, but also obviously with different types of measurements. So balloons, ground measurements, ship measurements, planes, aircraft, dedicated for atmospheric measurements, and obviously satellites as well. We've got loads of satellites now. And we cross-compare, we peer review papers, and then we put it all into the IPCC reports as a kind of global summary of how much we know. And that gets updated every few years. So a typical model looks like that. It looks like a simple cartoon, but the physics gets super complicated because every phenomenon that is shown here So currents, evaporation, rain, absorption, reflection, transmission, precipitation, aerosols, pollution, CO_2, oceanic currents, salinity of water, you name it, have an impact on the system. So you need to basically model all of that, cut your earth into a grid, and solve your complex differential equations. at the edge of every grid. And obviously, the finer the grid, the more complex the calculation you are going to have to solve. So you get 2 predictions that, for example, here tell you the temperatures on the planet at different time stamps. You can run them in the past and run them in the future at different spatial resolutions. And you can use supercomputers. So this is a picture of the Earth simulator to run those more complex calculations to try to reach more precise, I should probably say more accurate, make more accurate predictions. A new trend today is that scientists are using artificial intelligence to do weather forecasting as well as to do climate simulations. So obviously this is validated on existing data sets. So as you know, in this situation, the quality of what you're going to get is very much dependent on the quality of the data that you feed the models with. But surprisingly, climate scientists are actually quite surprised to see how good AI actually turns out to be for climate modeling. And it's also less computationally intensive. So there's a trade-off. But it's proving important. So it's definitely a new ave. You've got a lot of AI and mathematical scientists working in this area as well now. But obviously, what you want to be, you want to be not just trusting the models for the general, predictions, but also get a sense for, ideally you want to predict the edge cases. And the problem is that the edge case is the one that maybe AI will miss. So a lot of research and very fascinating research also in this area as well. And you can make more and more precise measurements with better and better calculations. What we observe and what we simulate looks like that. You have temperatures on the vertical axis over over time. So here we're talking about 2,000 years. And you can make simulations, you can make observations, you can match the two, and you can try to effectively use your model to then say, what if we change this CO_2 parameter? What if we remove the effect of this particular cloud? And you can try to look at the sensitivity of the model for the different parameters. And this is kind of a sensitivity analysis that shows you the different aspects, the different parts of the atmospheric system, that is responsible for the potential change in climate. And what we see is that basically mixed greenhouse gases is the largest component. You've got aerosols, clouds, maybe variability in the solar cycle as well. You've got some pollution here, interestingly, perhaps I can mention that, due to sulfur dioxide. And interestingly, pollution actually cools the climate. Pollution tends to reflect light right before it reaches the ground. So higher reflection means less absorption, means cooling effect. So if you reduce pollution, you actually accelerate warming. So obviously we're not going to keep the earth polluted because of this, but it's important to know that pollution and the effect of pollution in CO_2 could actually go against each other. And so as we are starting to measure the fact that as we reduce pollution effectively, we see the direct effect in the climate. So it was a surprise to a lot of people. Although the physics is simple, the magnitude of the effect was surprising. We're talking about 0.5 degrees on the whole system. And then you can run those models with different types of simulations. And the simulations could include different types of carbon emissions. So if you assume this amount of carbon emission in the next century, you're going to get that. If you assume more emissions, you're going to get that. And you feed those models into other sorts of economic models. And you can come up with different scenarios in terms of what climate you might end up in at the end, depending on your emission scenario. And you can also run, of course, forecasts that are to do with the cost of adaptation. And then economists are also looking at this very carefully. And you can run that for global surface temperature at the top. And there's lots of graphs here, but it's just to give you an idea. But you can run that for sea ice in the Arctic, for ocean acidity, ocean pH, which is important for the capture of CO_2 by the oceans, also another complex ocean atmosphere interplay, sea level change, you name it. All parameters can be placed in those models. And you can even imagine what the atmosphere would look like, or the Earth would look like, if you were to increase or decrease the temperature. And here it's an experiment where we assume that the Earth was 5 degrees cooler, and you can see pretty much the whole of the northern hemisphere is under ice. So it shows you that 5 degree amplitude is a massive amount. So what causes climate change is really quite established now, what causes anthropogenic climate change is the increase in CO_2 as well as methane, which come out as a result of the burning of fossil fuels. So it's really as simple as that. Fossil fuels, as you know, the chemical reaction for combustion, you transform a carbon-based molecule plus oxygen into water, CO_2, and some other carbon molecules. So CO_2 is a product, a byproduct of combustion. And the rate of burning of fossil fuels is really orders of magnitude faster than the rate of creation of fossil fuels, because fossil fuels really create over millions of years where life actually dies, get deposited, get transformed into oil and gas and all sorts of carbohydrates. And when you burn them at the rate at which we do, you obviously change the cycle, the fossil fuel cycle, which itself is a natural cycle. So we want to address climate for many reasons. Some might argue there's an ethical, moral reason for that. You might even go as far as saying it's existential, because potentially if you change the only planet that you have, and as you know currently there's no plan B for the Earth, there's no Earth #2 where we could get to. It's potentially existential, especially if you lose control over the system, especially if you have runaway effect. There's a lot of, I haven't had time to talk about this, but there are a lot of anxieties about positive feedback loops in the system. You don't want Antarctica to start to melt too much because the impact on sea level could really be really dramatic. So it's potentially existential, maybe not in the short term for the next few years, but if you're thinking 10, 50, 100 years, you really want as a civilization to be keeping an eye on that and be on top of that. And potentially, of course, economic and even political consequences. Of course, as always, for how humanity has managed to get through our problems, and that's just one of them, but it's not the first time that humanity is actually facing a big problem. So maybe it's my message here is to say that, because some of you, or maybe not you, but some of the young generation says, oh, it's so scary, we've got a climate problem, and it's the end. We're all going to die, and that's the end of time. But Well, that's one view of that, but it's not the first time that humanity is facing a big challenge by far. So we have to see it as a problem that we understand, and we can try to solve it. As always, in one way or another, technology in one form or another has often been the driving force for addressing issues. Often politicians, they try to say things or accompany movements, but usually the technology that has been invented is really the source. And so you want to be having your energy sources that are as clean in terms of CO2 emissions as possible. And the first one that comes to mind is nuclear fission, because it's carbon neutral, it's very efficient, it's very compact. You produce a massive amount of energy in a very short amount of space. And if we have a minute, I might show you a quick video about nuclear reactors, hydroelectricity, solar, wind, and nuclear fusion, but some question marks around wind and nuclear fusion. And the big issue is that they are intermittent. They vary during the day. So you can't always rely on them. It's quite complex. So that's a picture of a power station, a nuclear power station, a beautiful one. I'll show you a quick clip about how nuclear power stations work. They are really great. So I'll show you that in a second. Hydroelectricity, conversion of gravitational energy into electrical energy, It's extremely smart, but the capacity of hydroelectricity is already maximum, so there's not so much more we can do in many countries. Solar, wind, of course, as you know. And effectively we are there and we have to switch to using less fossil fuels and wonder whether our institutions alone can do the work, but I believe technology really is going to be offering solutions to this. So before we finish, I want to show you a quick, quick video on nuclear reactors, because some of you I know are interested in this. And actually, funny enough, I'm showing you this video because by pure coincidence, I saw this video by chance a couple of days ago, literally, which is someone who put together a video with music to explain how a nuclear reactor works with cool music on top of it. And hopefully that gives you an idea, like a very quick music-based summary of how a nuclear power station works. So I'm going to launch this. I think it's two minutes. And you have to pay attention to the lyrics. There's a lot of physics in this song. So let's see. Sci-fi, but it's really just a way to eat.

Ever wonder how nuclear power plants work? It sounds like sci-fi, but it's really just a way to eat water. It works like this. It all starts with uranium, though metal, micro rocks are fine and shaped in a tiny pellet. Each one's the size of a sugar cube. Holds as much energy as a ton of coal. The pellets get stacked in the fuel rods, which are just metal tubes. The rods get bundled together and loaded into the reactor car. Now here's the cool part. Uranium is unstable. These atoms want to break. The one splits, it releases heat into neutrons. That's called fission. Those neutrons hit nearby atoms and split them to more heat, more neutrons, more splits. Control rods made of boron slide in and out, absorbing neutrons. Rods and reaction slows emergency. So what happens with all that energy, the fuel rods are surrounded by water inside the reactor the fission heats the water which heats more water into steam spins to generate electricity to the giant cooling towers from the highway that's not smoke it's Could last over 200 years, and there's more dissolved in seawater than we ever need. Our nuclear reactor is dangerous, they can't have oxygen, but not nuclear explosion, that was bad, really bad, but technically it was a steam explosion. I got a photo of these acid, just a different society. What about the radiation? There's steel and concrete, keep it in, stored on site, steel and monitors. So why don't we build 4 reactors? They're expensive, 50 years of dollars, and a decade to construct, and a few high-profile disasters make the public nervous. Ninety-four reactors running.

So I'm just going to finish on this. So I have to say like this is really I literally saw this video two days ago and I thought I just cannot not show you because perhaps in 2 1/2 minutes you have the whole of the physics syllabus for this year. So I want to just finish on this picture that shows the Earth's atmosphere. You can see it's this tiny layer here. You can barely see the diffusion of visible light. It's a tiny, tiny layer that actually has a very big impact on life on Earth. And so there's a general message, of course, of protecting our system. in whatever way we can, and to use rational technological solutions for the best outcome, and to maximize a good outcome for our civilization. So thank you so much, and we'll see you soon in physics for my students. See you soon. Bye-bye. Thank you.