COMMISSIONER: Good morning. This morning we return to the topic of climate change and energy policy and I warmly welcome Professor Tom Wigley. Today's witness was part of our original plan some weeks ago when we had the witnesses for the first Commission's topics and the professor's recently returned to Adelaide and we're delighted that he could join us today. It is appropriate to add that this will not be the last time the Commission returns to the topic, it is in one of the later sessions likely to come forward as we address the outcomes of the Paris climate change negotiations which are due to take place in late November and early December. The outcome of those talks will certainly have implications for the inquiry that we are currently undertaking. Counsel.

MR JACOBI: Professor Tom Wigley is a professorial fellow at the University of Adelaide with over 40 years of experience in the discipline of climate science. He's previously served as a director of the climatic research unit at the University of East Anglia in the UK and a senior scientist at the National Centre for Atmospheric Research in Boulder Colorado of the United States. Over the years Professor Wigley has authored numerous publications relating to climate science and has been a key contributor to many reports by the intergovernmental panel for climate change IPCC and we call Professor Tom Wigley to the Commission.

COMMISSIONER: Professor, you've been monitoring climate change and temperature change in particular. On my understanding you've got some very recent data on that. Would you walk us through that please?

PROFESSOR WIGLEY: Yes. The diagram here is the first of two diagrams that I'm going to show and this is information that goes right up through September this year. It takes a little bit of time to get the data from the oceans and from the land areas together and average them over the globe, so we're always a month or two behind. And as I'll show in the next figure, the last few years have been record breaking years in terms of global mean temperature and this year, although it's not finished, we can say with a high degree of confidence that this year will be warmer than any other year in the observational record and considerably warmer than last year, which was also a record and the year before that, which was also a record. So the last – that will be three years in a row that we've had record-breaking temperatures in terms of global mean.

This first diagram just shows the progression of temperatures month by month for selected years that I'll show in the next diagram and just shows how much warmer 2015 is compared with these other extremely warm years. So if we go to the next diagram, this shows the temperature record developed by the National Oceanic and Atmospheric Administration in the United States. They seem to have been the first people to actually update things to the latest information available.  There are three organisations that produce temperature records like this and they all agree extremely well because they're using the same data.  They manipulate the data in slightly different ways but they come up with results that look very, very similar.  So you can see there that the last one, which is 2015 up through September is appreciably warmer than the previous year.  I just notice I made a little bit of a mistake there, that 2013 wasn't a record, it was actually the second warmest year on record but then that was beaten by 2014 and will be beaten again by 2015.

One of the things that people have highlighted in recent years in the sceptical literature is the so-called warming hiatus or the slow down in the rate of global mean warming.  It's pretty hard to see in a diagram now when you add a few warm years at the end then you know, you could draw a line from about 2004 or so, through to 2012 and it looks fairly flat but now we've started going up again.  We do know why there was that warming slow down and that is that the heat that would normally have stayed in the atmosphere went in to the deeper ocean and so the atmosphere warmed less than it would otherwise have done so, and that in turn is associated with the change in the vertical distribution of heat within the ocean column globally, across all the oceans of the world.  And that's something – a phenomenon that happens periodically as an element of natural variability, though rough time scale for those ocean changes is about 20 years, so we would have expected and did expect, that after about 15 or 20 years then we would get a bounce back warming.

And in fact, the projection would be that we will have a series of much warmer years over the next few decades and then of course continuing warmer and warmer as we increase the concentrations of greenhouse gases in the atmosphere.  So essentially people did predict that we would have warmer years now and we're having them now.  So it's actually quite a good endorsement of the validity of our understanding of the climate system.

MR JACOBI:   Can I just pick up from just the last part of your answer there?  In terms the predictions out in to the future, are you able to express a view, perhaps very generally about what the impacts are likely to be in terms of temperature in the absence of mitigation?

PROFESSOR WIGLEY:   Yes.  I think this is a bit of a hypothetical question because there's no doubt that we are going to do something about mitigating climate change and reducing the levels of the radioactive gases that affect the climate.  So there were a number of scenarios that have been put forward of what would happen in the absence of any policies to reduce the magnitude of climate change.  They're often referred to as business as usual scenarios but they're strictly no climate policy scenarios because some of the aspects that are incorporated are business as usual, so there's a slight difference and subtlety in the terminology there.  There's a great deal of uncertainty in what would happen in the absence of climate change. Sorry, in the absence of policies to reduce climate change. So one of the first set of scenarios that consider just these no climate policy issues had scenarios in the future where the concentration of carbon dioxide went to only like 500 parts per million and others went – it went to, by 2100, over 1,000 parts per million. They were all essentially accounting for uncertainties in how people behave, what the economy of the world's going to do and so on and so on. So there's a lot of uncertainty there.

But even at the low end, like say a 500 parts per million future, which is a possibility with a very, very low probability, the changes would be larger than anything that human beings have experienced and certainly larger than anything that has occurred even if you go back millions of years in to the geological past. There's uncertainty in how the atmosphere would change. There's even greater uncertainty what the impacts might be but some people have even used the word catastrophic, if we didn't do anything. I think that may be a little bit too extreme. The real problem is that there are certain areas of the world that could adapt to climate change quite rapidly and effectively. We live in one of those countries and essentially the OECD countries could adapt quite large changes in climate except perhaps for sea level around the coasts, little bit harder to adapt to. But countries like small island states, or Bangladesh or places like that which will experience sea level rise and they're low lying.

And certainly countries like Bangladesh, or in areas where there are tropical storms in the Bay of Bengal, the intensity of those storms is predicted to increase. May be not the frequency but already if you can imagine 50 centimetres of sea level rise and then a big powerful tropical storm coming up to Bangladesh then there are tens of millions of people who are going to be affected by circumstances like that. So that is just an indication of the seriousness of the problem if we don't do anything to mitigate climate change.

MR JACOBI: Can I perhaps pick one extreme which is business as usual, which you've identified as not being something that's likely to persist in steps being taken for abatement. But can we step to the other end which is what the effects would be likely to be, even if we took stringent measures?

PROFESSOR WIGLEY: Right. I think the next diagram will give you some idea of the consequences there. Okay. So this is a diagram that shows changes in global mean temperature and seal level rise for different possible stabilisation levels for carbon dioxide concentration in the atmosphere. The right-hand curve is where we stabilise the Co2 level at 450 parts per million and you can see that, if you look at the X axis there, that warms by about 1.3 degrees relative to now or to 2002 degrees relative to (indistinct) so this is the target that many people think we should aim for. There are many people who think that that's too high a concentration target, so people like Jim Hansen for example, a very famous climatologist, thinks we should aim for 350 parts per million and that's the middle curve there. You can see that in both of those cases sea level continues to rise, so stabilising temperature doesn't stabilise sea level rise and that's a really important point to make. The time scale for sea level change is pretty slow, but it's inexorable and it's something that has not really been considered in defining things like dangerous climate change, which is something that's written into the frame work convention on climate change, we should avoid dangerous interference in the climate system. Most people just use global mean temperature as an indication of how to define the dangerous level and Copenhagen Accord said two degrees warming relative to the preindustrial time is the threshold for dangerous interference, but if you incorporate sea level rise you can see that even if we could go back to 250 parts per million, which is 30 parts per million below the preindustrial level, we would still have continuing sea level rise. Basically because there are certain systems, big ice sheets like Antarctica and Greenland, that have very long time scales associated with them full ocean warming causes expansion and that operates on a very long time scale, so it's basically impossible to stabilise sea level rise. If we went back to a level of Co2 in the atmosphere below the preindustrial level sea level would still continue to rise as that diagram shows.

MR JACOBI: To round that diagram out can you just explain what the source is of that particular data that's referred to there or where that plot is drawn from?

PROFESSOR WIGLEY: The WRE stands for some stabilisation scenarios that I and some economist colleagues of mine developed back in 1996 and those are stabilisation emission pathways that stabilise the concentration of Co2 at different levels in the atmosphere. By the way if we were to try to stabilise at 250 parts per million we would have to suck Co2 out of the atmosphere clearly, but by sometime around the middle of the century we would have to be sucking Co2 out at the same rate that we're putting it in now and that would be some sort of challenge I would imagine, so these are results that are produced with a model that I developed that has been used extensively in IPCC reports because it's a very simple model, it only gives global mean information, the model is calibrated against much more sophisticated models so it's able to emulate the results in a very computationally efficient way, the results are much more sophisticated models.

MR JACOBI: Just so I'm right in understanding we're presently, given the current level of concentration of Co2, somewhere between the middle and the right-hand curve. Is that right?

PROFESSOR WIGLEY: Yes, that's about right. The present concentration of Co2 is about 400 parts per million, yes, so that means to get to the 350 we're going to have to go backwards and with a target of only 50 parts per million more than 400, where we are now, you can imagine that that's really challenging.

COMMISSIONER: What would the 550 look like on that graph?

PROFESSOR WIGLEY: Greater warming greater sea level rise and the sea level rise curve would run – essentially if you look at the bottom part of the curve there you can see that there's basically a straight line relationship at least up to 2050 or so between temperature and sea level rise.

COMMISSIONER: Yes.

PROFESSOR WIGLEY: That straight line relationship if you just want to extrapolate it out hundreds of years into the future the 550 case looks a little bit like that, it's bad.

MR JACOBI: We've just dealt with one model and perhaps if we can come to the models that underpin the Fifth Assessment Report.

PROFESSOR WIGLEY: Right.

MR JACOBI: I'm just interested to understand about perhaps the key challenges that are involved in climate science and predictions and the issues that are involved in the future development of those models, whether you can identify some of the key issues that arise.

PROFESSOR WIGLEY: I guess there are two primary issues here. One is trying to predict what's going to happen to the emissions of greenhouse gases and I mention that even for the so-called business as usual case there's a lot of uncertainty in predicting what's going to happen out for the next hundred years and of course the uncertainties accrue even more as we go century by century into the future, so these diagrams here go out to the year 2400. If I were to put uncertainty bounds on these diagrams just related to the emissions there would be a huge kind of triangle of uncertainty expanding from zero uncertainty at the bottom and getting wider and wider and those diagrams with their uncertainty bounds would overlap. One of the sources of uncertainty is not knowing what's going to happen to emissions either under a business as usual scenario or in response to policies and we do try to incorporate those uncertainties when we look at future changes in climate and it's possible to produce probabilistic projections of changes in climate and that sort of work's been done by a number of people over the last decade or so. Right, so there's uncertainty in what's going to happen to the emissions and concentrations of greenhouse gases in the atmosphere. Even if we knew that then there's a lot of uncertainties in how the climate system would respond.

MR JACOBI: And that's the issue of sensitivity?

PROFESSOR WIGLEY: The primary cause of uncertainty for future climate change if we knew what the emissions were is the climate sensitivity, which is the amount of warming that would eventually occur if we double the amount of carbon dioxide in the atmosphere and the most recent IPCC report didn't actually give a best estimate for that climate sensitivity, but from the information that you can see in that report you can back out roughly what that is and it would be about 2.2 or 2.3 degrees warming for a doubling of Co2. The previous report gave a best estimate of 3 degrees. My view is that there's no credible reason for changing from the 3 degrees and perhaps that's the reason why the IPCC in their latest report didn't give a central estimate because they realise that there's a lot of uncertainty in that and my view, as I said, is that the 3 degrees is still the best value for the climate sensitivity and that's based not only on model results and recent observations and calibrating models to observations, but that also is determined partly by the long time scale historical and geological past.

MR JACOBI: The Commission's already heard, and I will come to it in a minute, that the IPCC has used some RCP or these case scenarios and they're being used to inform policy and I'm just interested if there's an implication in terms of the sensitivity being a lower number than used previously does that have an implication in terms of the extent to which abatement would need to occur more quickly if one was to use the 2014 or - - -

PROFESSOR WIGLEY: If the sensitivity is lower then future climate change will be lower and therefore the mitigation required to stabilise at any particular level would be less, but even at the lowest possible level for the sensitivity, which is about 1.5 degrees for a doubling of Co2, we're still in dire straits in terms of future changes of climate, so mitigation and large scale mitigation and large magnitude mitigation would still be necessary even at the low end of the climate sensitivity range.

MR JACOBI: Yes. I was endeavouring to go the other way perhaps in the sense that if one has in fact under estimated the sensitivity is the implication in terms of abatement and the need for abatement greater?

PROFESSOR WIGLEY: Yes, much, much greater.

MR JACOBI: I'm just wondering about whether – we've heard some evidence about the RCP scenarios that are used to underpin. We've heard something about RCP 2.6 which we understand is consistent with the 450 parts per million and the warming is 2 degrees.

PROFESSOR WIGLEY: That's true.

MR JACOBI: We've heard something about RCP 8.5 and I'm just wondering perhaps whether you could explain the contrast between those two representative scenarios.

PROFESSOR WIGLEY: Yes, and I can give you some diagrams. When we finish this discussion I can email you some more information about those. RCP stands for Representative Concentration Pathway and climate modellers like to have a range of possible futures in order to test the bounds of sensitivity of their climate models, and the reason why the RCPs were developed and generated is partly because the climate modellers wanted a wider range of possibilities to get the extreme range of possibilities for future climate change. So it was the climate modellers that were responsible for the development of those RCPs, and in that sense, they weren't primarily developed for application to the policy issue.

So where did they get that information from? Well, the models that produce projections of emissions for different greenhouse gases and radiated reactive components like aerosols and so on are called integrated assessment models, and there are many integrated assessment models in the world. There are three of the better ones that are in the United States, but there may be 20 credible integrated assessment models worldwide and they produce a whole suite, even model by model, of many different scenarios with different possible policy options built in, or using the models to try and get an optimum policy to reach a particular target.

So there are hundreds of those scenarios of future emissions out there, and the people who were charged with selecting the RCPs had access to those many hundreds of scenarios and they chose scenarios that stabilised at about 450 parts per million, which is RCP 2.6, and then they chose a very large emissions scenario, which is RCP 8.5 which stabilises - well, which actually reaches the equivalency 02 radiative forcing of 8.5 watts per square metre in 2100. Nobody is trying to put probability bounds on those numbers, and the reason why they're not so useful for the policy area is because they're all developed by different modelling groups, so they're not directly comparable.

There is a set of scenarios that was developed in the USA a number of years ago under a program called the Climate Change Science Program, and the scenarios developed by CCSP were set up quite differently and, I think, in a much better way. I'm not criticising the development of the RCPs in that regard, because they did the best job that they could with the available information and the time available, but the US project said to three modelling groups in the United States, "First of all, will you develop a no-climate policy emission scenario. What would happen if there were no policies to reduce or mitigate climate change?"

So the three models produced these kind of business-as-usual baseline scenarios, and then they were charged with trying to introduce policies that would stabilise radiative forcing at different levels relative to what the business-as-usual value was, and the lowest level that they used was the 450 parts per million case. These models used optimisation algorithms to find the cost effective pathway to reach these different stabilisation levels and they used different methods for optimising the pathways into the future and they made different assumptions about costs of energy technology.

In one of the cases they assumed that public opinion would preclude the rapid development of nuclear energy, so in that particular modelling case there is very little growth in nuclear. So how do they get to the same point if they don't have nuclear? In this particular case, there is actually very little growth in renewable energy too, which means they've got to do something rather dramatic somewhere else in their framework in order to get to whatever stabilisation level was their target. In that particular model, they reached that point by having very large changes in end-use efficiency for energy technology. And again, I can give you some diagrams that quantify that sort of information later.

MR JACOBI: We've had a number of years of experience since the RCPs were released. I'm just interested to understand how we're tracking as against the RCPs themselves.

PROFESSOR WIGLEY: Right. If you compare the two most important gases in terms of affecting climate, that's carbon dioxide, which is the most powerful - or not the most powerful greenhouse gas, but the one that has the greatest effect on climate presently and in the future - and sulphur dioxide which produces sulphate aerosols that have a strong cooling effect. So just considering those two, captures a large part of what might happened in the future.

So what one can do is compare the projected emissions of carbon dioxide and sulphur dioxide in the RCP scenarios with what has actually happened, and in both cases - right. For carbon dioxide, those RCP scenarios underestimate by quite large amounts the emissions of carbon dioxide up to the present, and they overestimate the amount of sulphur dioxide, which means that they're overestimating the cooling and underestimating the warming, so both acting in the same direction. Ironically, the RCP 8.5, which I think is the least realistic of those scenarios, is best in estimating changes in the emissions of sulphur dioxide and carbon dioxide up to the present day.

MR JACOBI: Do those differences have an implication in terms of forming a view about the need for abatement as against those RCP scenarios now? Do they imply that you need, in essence, to go harder?

PROFESSOR WIGLEY: Yes, absolutely, and in fact you need to go a great deal harder. The error now in emissions of carbon dioxide, if we just compare the RCPs with the observations - they are available up to 2013 or 2014 - then the present - I think the value of emissions of carbon dioxide for 2013 or 14, I can't remember which year, is about 10 gigatonnes of carbon, and if you look at the RCPs, RCP 8.5 might be 9 or 8.5 or something like that, and RCP 2.6 and 4.5 and 6 are even less than that. So we're way below by maybe anything from 10 to 15 or 20% below what has actually happened if you compare those projections with what has actually happened. Well, that's just going to make it much harder to reach any future target for future climate or future radiative forcing or future carbon dioxide concentration levels in the atmosphere.

COMMISSIONER: It might be a good time to understand what is actually happening in Paris, the process. Are you familiar with that?

PROFESSOR WIGLEY: Yes. I'm fairly familiar with that.

COMMISSIONER: It would be interesting to walk through where the countries now have made their policy decisions and how that has been brought together and what you expect to see in Paris.

PROFESSOR WIGLEY: Right. So there are about 190 countries that have signed onto the Framework Convention on Climate Change, and about 150 of those countries have submitted - what are they called?

MR JACOBI: INDCs?

PROFESSOR WIGLEY: Yes, INDCs, and it stands for Intended Nationally Determined - not commitment, but--

MR JACOBI: I think it is Commitments. I think it might be.

PROFESSOR WIGLEY: Okay. It could be Contribution, but you can tell me by looking at that. I guess the key word here is "intended", and often the best of good intentions fall by the wayside and are never achieved. Right. So 150 countries have put forward their plans for a target for emissions in the year 2030, or around 2030. Because of the political problems of getting people to agree to all do the same thing, then there are a number of different ways that people have couched their commitment or their contribution in the year 2030 and I can tell you a breakdown of those.

Now the best way to do this, which is what Australia has done and the United

States and many other countries, is to say in 2030 we will reduce our emissions relative to some particular base year. And unfortunately people who have given that information have used it from base years, so people have – about a third of the people have used 1990 as a base year, 20 per cent have used 2005, some people have used 2010, 2015 and so on. So that makes it hard to compare these commitments. Right, so other countries, again about a third of the countries have given their commitment in terms of a business as usual scenario. So they say that we will reduce our emissions by a certain percentage, relative to what would have happened in the absence of climate policies. Other countries have just given notional ideas of how they would reduce emissions. They'd say, well we're going to reduce carbon intensity by a certain amount, we're going to do – China's an interesting example, where they listed hundreds of different ways that they can reduce emissions.

Some lesser-developed countries have said, well this is the target we'd like to achieve but we're not going to do it unless you give us a lot of money. And then there are some other countries that have given such vague information that you can't interpret it anyway. So a challenge there is how do you put all this information together, this disparate information together, and work out what the consequences of all of these targets might be for future climate change. And a few organisations have tried to do that. And a colleague of mine has actually been doing this work for the Framework Convention and I can tell you the result. And that is that, if you try to put all this information together and then make some reasonable assumption of what might happen after 2030 then the stabilisation for global mean temperature would be at a level of about 2.7 degrees. So even if all those commitments were actually made and the targets achieved, we would still be over the two-degree warming target and that means we've got to do even more after 2030.

MR JACOBI: 2.7 degrees, that's consistent somewhere between 500 and 550 parts per million, is that right?

PROFESSOR WIGLEY: Yes. That's about right I would say. I can actually – from this diagram, the difference – if you look at 2100 in the 350 and 450 case then in 2100 the temperature is about one degree warming relative to 2000 and it's about 1.5, so for every 100 parts per million there's about an extra half a degree warming. So that means that the 2.7 corresponds to maybe 570 parts per million stabilisation.

MR JACOBI: So I think that might pre-empt my next question which was, am I correct to understand that in essence the current targets are insufficient to achieve the 450 outcome?

PROFESSOR WIGLEY: Correct.

MR JACOBI: I'm just interested to just come back to the question of the target itself and I'm just wondering whether you might be able to explain what you understand the origin of the two degrees to be? And whether there are issues in any event?

PROFESSOR WIGLEY: Yes.

MR JACOBI: I think you referred in your earlier answer to there being some disagreement even about whether two degrees is adequate?

PROFESSOR WIGLEY: Well, my view is certainly that two degrees is not adequate and I think that's echoed by a number of other climate scientists as well. But this is international politics and just getting countries to agree, even in a non-binding way, to a target of two degrees is an amazing and wonderful achievement and now we can work on trying to achieve a more realistic and lower warming target. No matter how low that target is, sea levels are going to continue to rise on a century timescale, so that's a target that is probably unachievable stabilisings. Sea level rise. How did two degrees arise? Well, there are people have written history of the two degree warming target and my awareness of this came when I was working in England and the two degree target actually was developed earlier than my awareness of this. But I became aware of it as part of European community policy. And it was really strongly endorsed by the European community but particularly by the person who was the Minister for whatever the equivalent title is for the environment, who is an Italian and he believed very strongly that we had to have a fairly stringent target. And at that time, two degrees seemed like a pretty tough target and it still is a pretty tough target.

But people thought at that time that it might be a sufficient target. Well, I think there's a lot of people who don't agree with that any more. But you've got to start somewhere. And starting with an agreement for 150 countries to endorse the two-degree target, which is not a binding target in any way, which leads me to another comment I need to make about the targets. I mean I think that's an amazing political achievement. It has taken since 1992 to get to this point, more than 20 years, but hopefully we'll move on more rapidly in the future as climate continues to warm and it becomes more obvious that the modellers are actually right, or maybe underestimating the magnitude of warming and we've got to do something pretty dramatic about it. One of the things about the INDC is that there's a discussion going on about whether they should be mandatory or optional. Many countries have said that they should be legally binding targets. There's another issue of how you enforce legally binding targets in an international level like that, which people are trying to address. But the United States, as an example of a number of other countries, have said that they will not accept legally binding targets. I think the United Kingdom has said, we will only accept legally binding targets. So these are poles apart and this is where the Paris COP 21 meeting is going to have fun trying to compromise between these extreme views. There are all sorts of things that can happen.

I'll give you an example, the US might say well okay we'll back down on requiring a non-binding target. We'll accept legally binding targets but we want other countries to do something to kind of balance this out. So they might say, well we'll only move away from our demand there if China agrees to reduce its emissions more rapidly than they have said they're going to. Now China is a very interesting case because what China's commitment is but non-binding commitment, is that they will peak out their emissions in the year 2030 and then reduce emissions after that. Well, I think China's got to do – probably do better than that, along with all the other countries in the world because we're not even getting to the two-degree target. So everybody's got to pull some weight there in order to get that target down lower. That might not happen in Paris but it might happen subsequent to Paris.

I mean you have to allow the lesser developed, or the developing countries of the world to develop their economies and you've got to admit that most of the problem is a problem that we in the OECD and developed countries have caused and that China has – although the Chinese emissions of carbon dioxide now are greater than any other country, their cumulative emissions and their per capita emissions are much less than other countries like the United States and the European Union and so on.

So you've got to account for their concerns about the unfairness of asking China to reduce their emissions and maybe have serious economic consequences in terms of the growth of their economies given what we've already done in - well, even in Australia in terms of per capita emissions, but the USA and Europe and all those places. So I'm sympathetic to the Chinese and the Indian concerns about mitigating emissions and mitigating climate and yet somehow allowing their economies to grow at a rate similar to what has been happening in the last few decades.

MR JACOBI: Before we move onto specific abatement strategies, you've expressed a view that although there is consensus on the emissions reductions required to avoid crossing this 2 degree limit, there is some doubt about whether the perceived requirements are correct. I'm just wondering whether you might explain the reason for that view.

PROFESSOR WIGLEY: You might have to rephrase that question again.

MR JACOBI: All right. The view you expressed is that there is agreement on the emissions reductions required to avoid global mean degrees, but whether the perceived requirements are correct is open to considerable doubt.

PROFESSOR WIGLEY: Okay. So this is not the question, "Is the 2 degrees target the right target?" It's, "Is the way we get there the best possible way?" Right. Well, I think there is an issue about whether we can even get there at all, but the differences are in the energy strategies that might be used in order to reach the 2-degree maximum warming relative to pre-industrial times. So there are some people who think that globally it's possible to do this with so-called renewable energy alone. So that is things like hydro, wind, solar and so on, and in fact there is an IPCC report on renewable energy that suggests that we can do that, although that report has been criticised by a number of people in the open literature, and I feel that it was very strongly biased actually, but that's a rather complicated issue that there is better information in the literature criticising that report than I could possibly do.

Right. So can we get there with renewable energy globally? There are a number of papers that say that we can't do that and that we will need, in particular, to develop nuclear energy. My view, based on reading the literature and talking to many people in this area, is that nuclear energy must play a major role in future carbon-free energy strategy.

Right. What are the arguments against nuclear energy? Many people advocate renewable energy just don’t say anything about nuclear energy at all, and if you look at the documentation for the INDCs, many countries do mention renewable energy and only one country mentions nuclear as part of their portfolio and that's China. Other countries don’t say anything about energy technology at all. In fact most countries don’t say anything about the technology requirements at all. They're basically accepting the 2 degree and they're saying, "This is what we can do to reduce emissions, but we're not going to tell you too much about how we're going to do that."

Okay. So what are the arguments against nuclear? Let's see. One of them is the issue of proliferation, and that is that developing nuclear power generation technology might mean that there is radioactive material that could be stolen or used in order to develop bombs. That is not correct, and the reason why it's not correct is because the amount - well, there are two types of weapon: bombs that use plutonium and bombs that use uranium-235. For U-235 weapons, the concentration of U-235 has to be relative to 238. It has to be 50, 60, 70%. The U-235 concentration in nuclear reactors is 3 to 4%. So there's a vast difference between reactor-grade uranium and bomb-grade uranium and you would have to be technologically very advanced to be able to take reactor-grade uranium and then enrich it to produce bomb-grade uranium.

The other issue is plutonium. You can make weapons out of plutonium, and where do you get the plutonium from? Well, your reactors produce plutonium. So spent nuclear fuel has a lot of plutonium, which there's a serious problem right now for the United Kingdom. There's a lot of plutonium and they want to get rid of it somehow, but that plutonium is seriously contaminated or poisoned by other isotopes of plutonium. So you have to separate out the various isotopes of plutonium in order to produce plutonium that can be used for bombs, and again, that's technologically really advanced problem that almost no countries in the world can do other than countries like France, the United States and so on. So to be able to use waste material or fuel material from reactors to make bombs is just technologically impossible. So it's kind of crazy.

Now, there are enrichment technologies that one - okay. How do we enrich uranium now? We basically use diffusion technology, but there are laser enrichment methods that could be used and - - -

MR JACOBI: The Commission has heard about those in the last week.

PROFESSOR WIGLEY: Yes. Well, you might not have heard about CRISLA. Have you heard about CRISLA? No. Okay. There's a laser enrichment technology that has been demonstrated at a desktop level, but hasn't been demonstrated as being commercially viable, at scale, that is. So things that you can do in a lab doesn't necessarily mean you can scale them up to do them commercially. I can't remember what CRISLA stands for, but this is a slightly different type of laser technology, and you probably heard about what SILEX is, what it's called.

MR JACOBI: Yes.

PROFESSOR WIGLEY: Well, one of the people who worked on SILEX is a person who developed the CRISLA technology, and he and a number of other people are of the view that that is not a scalable technology. So if people have been telling you that SILEX is the pathway to enrichment in the future, then there are other people who will tell you that it is not the pathway and it's just not scalable. CRISLA was developed to make a scalable technology. It turns out that it's very cheap and that it can be used to produce bomb-grade material. So if a rogue country really wanted to produce bombs, then they should go back to the drawing board. I shouldn't give away secrets like this, I suppose. Rather than diffusion enrichment, there are other technologies that could be used much more easily for making bomb material, so that's a real concern with more efficient and cost effective enrichment technologies. The proliferation risks associated with those are much more serious than the proliferation risks associated with present enrichment technology, so that's a problem that the Department of Energy is well aware of and they have a lot of people who are looking at those particular issues. The same would apply to SILEX to some degree except that, as I've said, I mean a lot of people don't think that can be scaled up, but there are other laser enrichment technologies that might be scalable, so that's a serious concern.

Another issue is the cost of nuclear and I can show you another diagram, I think it's a little way – this one here. This is from a paper that was published in 2011 I think, so it's information that applies to about 2010 where the authors of this paper, and the main author is a guy called Martin Nicholson who lives in New South Wales, and so they've looked through the literature and got the so-called levelised cost of electricity values for a whole range of different technologies and this is a summary of the levelised cost of electricity for base load electricity and you can see that I guess the really important things are the dark blue curve, which is the cost in dollars per megawatt hour, that is about the same cost for base load electricity as efficient coal fire electricity. The other technology that's been used quite recently for developing carbon free energy is solar thermal and I'll show you some more information about solar thermal, but you can see that the cost of solar thermal per unit of electricity production is much, much greater in this review than nuclear, so the cost argument is really hard to endorse. I think if I go to the next diagram - - -

MR JACOBI: I don't think it's in there.

PROFESSOR WIGLEY: No, I don't think it's in there. Let me just give you some information verbally. Very recently the biggest solar thermal power station in the world was - - -

MR JACOBI: This is Ivanpah?

PROFESSOR WIGLEY: - - - finished and come online and it's a place called Ivanpah in a very sunny part of California, so that – I'll just change my glasses and I can read some information. You've got this information even though it's not on the screen. This is a solar thermal power plant and it's 392 megawatts, which is about a third of the power of most coal fired and nuclear power stations. The cost of Ivanpah was $2.2 billion, but in only produces electricity about 30 per cent of the time, so you can work out what the cost of energy from this solar power station was per gigawatt of electricity and it's about $18 billion, so compare that with the range of estimates for the cost per gigawatt of nuclear energy. They range from maybe $8 billion per gigawatt down to – the Chinese believe that they can produce nuclear power at $1.7 billion per gigawatt, that's one tenth of the cost of power generation at Ivanpah, which is the most up to date, most modern solar thermal power station and biggest solar thermal power station in the world. That power station is only producing electricity 30 per cent of the time, so what they have is they use gas backup, so that doesn't mean they're using gas for the whole 70 per cent of the time, so part of the time the power station won't be generating electricity and the real issue is how one generates peak power electricity at times when there's peak demand. Solar power stations aren't necessarily producing electricity at the time of peak demand and they're certainly not producing what's called base load electricity, which is power at a stable level 24 hours a day.

It is possible that people will develop energy storage technologies that allow people with solar power or wind power to put electricity when it's not being used for other purposes in to battery technology or molten salt technology and there are a number of technological schemes, some of which have actually been employed, like there's a solar power station in Spain that has a molten salt storage capacity, but the cost of that power station was $25 billion per gigawatt of electricity, so that was even more expensive and part of the additional expense was because of the storage technology required.

MR JACOBI: I was just wondering perhaps if I can interrupt there and bring us back to – I think we've got a table that might assist us with explaining this, which is - - -

PROFESSOR WIGLEY: Right, yes.

MR JACOBI: I wonder whether you might be able to explain your view about the implications about the intensity of carbon emissions from electricity from other countries and whether that has any particular implications for Australia.

PROFESSOR WIGLEY: Is that the diagram?

MR JACOBI: Yes, that's the one, it's up on the screen.

PROFESSOR WIGLEY: That one on the screen, right. What this table shows is a breakdown of energy use essentially by different - - -

MR JACOBI: Yes, by sector.

PROFESSOR WIGLEY: Therefore by sector for different countries and – it's a while since I've looked at this.

MR JACOBI: Do you have a view about whether or not there's a relevant comparison that could be drawn between or an implication that could be drawn from the circumstances in France perhaps by comparison to the circumstances in Germany?

PROFESSOR WIGLEY: Yes. France produces about 80 per cent of electricity with nuclear and France went from – I don't know that I've got exactly the right figures, but they went from 10 per cent nuclear to 80 per cent nuclear in a very short period of time, so they built a lot of power stations of the same type over a very short period of time. There's another good example of this and that's Sweden where they went from no nuclear power and no nuclear technology at all to becoming largely nuclear over a period of six years or something like that. This all relates to how quickly can we build nuclear power stations, so there are examples where people, if they're motivated enough, will build nuclear power stations very quickly. Germany had roughly I think maybe 20 per cent nuclear, still has roughly 20 per cent nuclear, but they've decided in their wisdom to close down all of their nuclear power stations and as a consequence they're going to be more dependent on coal and they are currently opening up some of their brown coal mines that have been mothballed to be able to produce more coal to reactivate mothballed coal fired power stations.

One of the ironies with France is that even though they have a lot of nuclear they still plan to reduce their amount of nuclear technology over the commitment period to 2030 and I'm not sure of the logic of that decision, but France has made strong commitments towards solar energy, to the extent that they've done some things that I think are quite strange. So people who have solar power on their rooftops and things like that can then, if they're not using all that power themselves they can sell it back to the grid via the feed in tariff concept. So France has allowed people to fix a price for feed in tariffs that is very high and for people that got on to that early, I don't know whether this still holds but they were able to lock in a feed in tariff that might be equivalent to 20 cents per kilowatt hour where nuclear energy currently in France is producing electricity at six to eight cents per kilowatt hour. That's a very bizarre decision to abandon cheap nuclear to more expensive solar technology. I have no idea why they do things like that. But usually there are political groups who are ideologically opposed to nuclear; this is my personal view, that then can influence the decision-making process for future energy technology.

And of course that's really the reason why nuclear technology is currently not allowed, under legislation in Australia, I mean that was a political decision made jointly by the National Democratic Party that doesn't exist any more I don't think, and the Greens. So the government, in order to get them to vote with them on certain issues, agreed to amendments to a couple of bits of legislation that were introduced in the late 1990s. One of the amendments was that there should be no nuclear power generation in Australia.

MR JACOBI: Can we just go to – I think we've got one last chart and this shows the output of, I think a model that you've already referred to, the miniCAM IAM model and I'm just wondering whether you might be able to explain the implications of that particular model to the Commission?

PROFESSOR WIGLEY: Yes. This is one of the models that was used in the climate change science programme in the United States and as I mentioned, three integrated assessment modelling groups were charged with developing a business as usual scenario and then applying increasingly stringent policies to educe emissions to get down to different stabilisation levels. This diagram shows you how the most stringent of those policy targets was achieved in this particular model. If you look at the other two models then the breakdown is quite different. Now even in the no policy scenario there was development of carbon free technology and if you look at the second band there, it says "spontaneous" and the "biomass" section, the "renewable" section and the "nuclear" section have thin lines in the middle of their little triangular piece and the upper part of that is the increase in that energy technology that would occur spontaneously in the absence of any climate policy. If you look at renewables, you can see that actually most of the increase in renewable technology, in this model, occurs spontaneously. The reason why that happens is because renewable technology prices go down in the future and at some point in the future, wind and solar in this model become competitive with coal and fossil fuel based generations. So a lot of that can happen spontaneously.

In this particular model, the cost of nuclear does not change over time, which I think is unrealistic. But even so, half of the development of nuclear technology occurs in the absence of policies. So if we start with the black line; that is the primary energy projection for the future, up to 2100 in the absence of policy. Then there is a reduction in the primary energy requirement due to changes in the demand for electricity and demand for power. Part of that is improvements in end use efficiency for example, which reduces demand. That is not the only reason. Then the next – this is the biomass segment and you can see quite a lot of the target and a fair fraction of which is policy driven is associated with the growth of biomass-produced energy. Not just for – mainly for transportation.

Renewables, most of that is for electricity production and again, it's a fairly large segment achieving the stabilisation target comes from developing renewable energy. A fair amount comes from developing nuclear energy and then quite a lot; in fact the biggest section comes from carbon capture and storage. Again, these results are all model specific and different models will have different ways of apportioning these ways of achieving the particular target. I've shown the breakdown of CCS in to coal, gas and oil, so in this model actually some electricity is produce with oil fired generation and then you can capture the carbon from any form of electricity production and stick it in the ground through carbon capture.

MR JACOBI: Sorry. Can I just pick up on some specific aspects? As I understand a level one case is a particular climate mitigation scenario?

PROFESSOR WIGLEY: Correct. The level one case is what corresponds most closely to the two-degree target. So it's a 450 parts per million equivalent CO2 level, which is roughly equal to the two-degree target. So this is what's required in this model in order to reach that target. Then under the blue line is the residual CO2 emitting energy, broken down in to coal, oil and gas and you can see that in this model, coal is phased out over the next 50 years and gas – I think if this were done – this now, again, the gas component would be greater. But the CO2 emitting energy curve would be the same but we're now exploiting gas, through fracking and things like that, and that really wasn't on the table to the degree that it is now, back in 2006/2007 when this work was done. So the breakdown of coal oil and gas would change if one repeated this but the blue curve would stay the same because that's what required to reach this two-degree target. The breakdown of biomass renewables nuclear and CCS would also change a little bit because things have moved on in the last decade or so in terms of the costs of those technologies and our ability to exploit those technologies.

Now different models give different results here. But this is indicative of a pathway to get to the two-degree target. The fact that different models give different pathways, different breakdowns in terms of carbon free technology just gives you some idea of the uncertainties involved in predicting future energy technology changes. I did mention earlier that one of the models, the model from Massachusetts Institute of Technology has a very, very small contribution from nuclear and renewables. Nuclear because they think that public opinion will preclude rapid development of nuclear, which may be correct. But for some reason they exploit renewables hardly at all, so how do they make up that big gap? Well, in that model, the policy driven demand reductions are more than double the amount in the miniCAM model. So if you don't get it one way then you have to get it some other way because all these models are trying to drive their models to the same target.

MR JACOBI: I am right in understanding that the upshot of this is that, even if you agree on target, there is going to be uncertainty in terms of how you're going to achieve it.

PROFESSOR WIGLEY: Yes. Big, big uncertainties, which is a two-edge sword really. It means that there are a lot of options out there, so that ought to make it a little easier. If one model can say, "We're going to have a large policy-driven demand reduction component," then if you apply that along with the nuclear renewables from this and the CCS from this, then you could go well below the 2-degree target. So, yes, in a way, uncertainties can be looked at as something positive that could be exploited in the future.

MR JACOBI: Am I also right in understanding that the upshot of all of this is that we would still be using carbon-based fuels but with carbon capture and storage significantly into the future on that model?

PROFESSOR WIGLEY: Yes, and so you can see that the red curve above the blue curve, which actually stays level and then rises a little bit towards the end of the century, is the amount of primary energy that is being developed using fossil fuels.

COMMISSIONER: Professor Wigley, thank you very much for your evidence. We'll adjourn at 10 past 10.

PROFESSOR WIGLEY: Thank you for the questions and for listening to my sometimes longwinded answers.

**MATTER ADJOURNED AT 10.11 AM ACCORDINGLY**