NUCLEAR FUEL CYCLE ROYAL COMMISSION

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TRANSCRIPT OF PROCEEDINGS

ADELAIDE

8.01 AM, THURSDAY, 1 OCTOBER 2015

DAY SEVEN

PROCEEDINGS RECORDED BY SPARK AND CANNON

COMMISSIONER: Good morning, I welcome you back to day 2 of topic 4, low carbon energy generation options and I warmly welcome from the US, Dr Makhijani. Mr Jacobi.

MR JACOBI: The Institute for Energy and Environmental Research, the IEER, is a US based organisation that provides activists, policy makers, journalists and the public with understandable and accurate scientific and technical information on energy and environmental issues. Dr Makhijani is president of the IEER and holds a PhD in engineering specialising in nuclear fusion from the University of California, Berkeley, and we call Dr Makhijani to the Commission.

COMMISSIONER: Might I start perhaps with your conclusion which says low carbon attributes for nuclear energy has no environmental or economic value. Perhaps you could just run through broadly what you mean by that.

DR MAKHIJANI: What I mean by that is if you can't deploy it, it has no environmental value. I mean, in theory, as I say, nuclear energy is a low carbon energy resource, but when you look at whether you can deploy it to do anything and to accomplish climate goals, I think it's most inadvisable to pursue that path on a number of grounds which I explained in my paper briefly, obviously it's a short paper, but which I can go into more depth with you.

MR JACOBI: Perhaps if we can pick that up and we'll just go through it piece by piece.

DR MAKHIJANI: Let me say one - you know, in the 1950s or 1970s solar energy was, you know, maybe two orders or three orders or maybe be more expensive. If you couldn't deploy it, it had no environmental value. In theory on paper you could say, yes, maybe, but you couldn't actually use it to solve any environmental problems. That's the sense in which I said it.

MR JACOBI: Perhaps if we can start from the perspective - and I think we might be getting some feedback. Is the audio okay at your end, Dr Makhijani?

DR MAKHIJANI: Yes.

MR JACOBI: Perhaps we can start in terms of the sort of time frames that you are of the view that we for abatement to be taken. Do you have a view about the sort of time frames that we have against the issues of deployability that you have mentioned?

DR MAKHIJANI: I think for developed countries it would be very good, advisable and necessary, I think, as this crisis develops to go to essentially an emissions free energy system by the middle of the century at the latest. I think that as, you know, the earlier reductions in greenhouse gases produce a larger climate benefit so the earlier you can do it, the better. As I indicated in the last part of my paper, I think technological progress has been so rapid that we could accomplish almost all of it by 2040. There may be sort of nooks and crevices where there might be natural gas or there might be specialised applications of petroleum, lubricating fuel, and so on, where you might need some fossil fuels, but when I say essentially all I mean 90 per cent, 95 per cent elimination plus.

MR JACOBI: Do you have a view about, given the sort of time frames that you have talked about, the sorts of technologies that we need to contemplate or consider with respect to making those sorts of abatements.

DR MAKHIJANI: Yes. The way I look at the problem is a lot of people say, "Well, we should have all of the above. We should have nuclear, we should have solar, we should have wind." Energy is not a smorgasbord. Energy is a system, specially electricity is a system, electrons must crowd, as you know, you know, it must be instantaneously balanced at all times otherwise you get into trouble. So the system has to be tuned. The petroleum transportation system today is relatively independent of the electricity system. What we need to get rid of, the petroleum electrify that, in my view at least in there are various ways to do it.

So I think if you look at it as a system then you look at the main low carbon sources that you have and their attributes and how they are going to work together. Now, in the case of solar and wind, obviously they are very large energy resources, nuclear also is a very large energy resource, and then you have issues related to each particular type of energy supply. It creates issues on the demand side, it creates issues on the economic side, it creates issues on the timing side, and in the case of solar and wind you clearly have to attend to the technologies to address the variability issues and ensure that your system remains reliable.

These are issues that I have been studying intensively since about 2006. Since about 2007 I am convinced - in 2007 I was convinced they were solvable. Today I think we have the technologies at hand, some of them need some cost reduction, but not great.

MR JACOBI: If I can come to maturity of the technologies that we ought be considering. When it comes to nuclear, do you think that the time limit for deployability imposes a limit on the sorts of technologies that we ought be contemplating?

DR MAKHIJANI: I think if you look at the time limits there's only one, the water moderated technology is the only technology that is mature enough that you could deploy it in theory, you know, with sufficient money, in the timescale necessary. I don't think any of the other technologies can be deployed, for instance, sodium cooled reactors, I mentioned, you know, we spent $100 billion and 60 years plus trying to commercialise it and not even solve all the reliability problems. Liquid fuel, chlorine reactors, also face large timescales for sorting out the problems, proving them, you know, making sure that you won't have nasty surprises and so on.

I have talked to the people in the nuclear industry so I don't develop my opinions in a vacuum only talking to people about solar energy or anything like that. I don't go to the Solar Energy Association for nuclear, so I talked to somebody who had long worked in the Nuclear Regulatory Commission, for example, he's a friend of mine, and I asked him, "How long would it take to develop rules, regulations and risk estimates so the Nuclear Regulatory Commission could effectively regulate liquid fuel reactors?" 10 years order of magnitude. So you have got 10 years to develop regulations, 10 years to develop a prototype, if all goes well you've already - you have lost the game.

MR JACOBI: I'll come back to the issues of licensing in a minute more generally with respect to water moderated plants, but can I come back to the issue of deployability of light water reactors. I am just wondering about whether you have a view about whether given their maturity, what's the basis for your view about their deployability.

DR MAKHIJANI: Well, you know, in theory the technology is pretty mature. I mean, we have got about 400 of these reactors employed around the world. Most of them are working pretty well. They generate quite a lot of the world's electricity, in this country it's about 20 per cent, in France it’s 75, 80 per cent. I have studied the French system. I do know French; I’ve spoken about this in France with regulators in France and Nepal. But the problems of deployability recall around – so the Three Mile Island accident and the Chernobyl accident revealed certain deficiencies in the existing system. So various modified designs, the AP-1000 here, the EPR in France were put forward to address these problems and supposedly resolve them. In the United States we also have streamlined licensing procedures where instead of two licences now only one licence is required, construction and operating licence at once. But in practice we see that they have not actually resolved the issues. We still have delays, we still have cost over runs, we’re still talking 10 years, or more than 10 years, the Finnish reactor is going to be more than 10 years. I think the reactors here in the United States are also going to be likely more than 10 years before they can be deployed and of course then the costs spiral out of control. Then you also have CO_2 emissions going on in the meantime, half a reactor produces nothing for you. Half a solar farm, if you do it – if you phase it right, produces half the electricity for you.

One of the big practical problems with nuclear energy, and we will talk about small reactors, I am sure, is that current proven deployed designs are all on the order of 1,000 megawatts, 1,000, 1,100, 1,200, EPR is 1,600. They are so large and they take so long to build that a lot depends on the reliability of your electricity forecasts. I know the electricity forecast in the United States pretty well, I have been following it not every year and for all utilities certainly but pretty regularly for more than 40 years now. Since 1973 the forecasts made by utilities, even though they have made many improvements and integrated resource planning and all that, have generally been quite poor. Usually the way utilities do it, they are over estimates. Perhaps, you know to guard against under supply. Understandable? Maybe. But what happens is you wind up in situations where you have over supply of electricity, your demand is not what it was and you find you have – you are building reactors you don't need. We cancelled, I think around 100 reactors at various stages of planning and construction in the United States in the first wave. I think about 115 or 120 were actually completed and started.

So it's not a very good record in terms of planning. So it's not about whether light water reactors work, it is what it takes to take a light water reactor of the type that we have and deploy it in an existing electricity system and the record for that continues to be very bad. I mean I say very bad advisedly if you look at Finland, if you look at Flamanville, if you look at the United States and so on.

COMMISSIONER: Yes. But if I looked Professor Makhijani, if I looked at the UAE for instance, would that give us a different outcome?

DR MAKHIJANI: United Arab Emirates?

COMMISSIONER: Yes.

DR MAKHIJANI: No, I must say I've not studied the United Arab Emirates. So far, they don't have an operating reactor yet. They are constructing Korean reactors, I believe.

COMMISSIONER: Yes.

DR MAKHIJANI: The – I'm not saying it's not possible to deploy new reactors. Certainly it is possible to deploy new reactors, it is being done. The Chinese are doing it; there are 25 reactors under construction. They have deployed a number of reactors in the last few years. I am saying if you look at the pace of deployment worldwide, even with those who are very determined to do it, like the Chinese, and you look at the scale of the need, those two don't match up. Then if you look at the scale of the need and look at the practical implications of where you are headed on a number of different fronts, I think the problems become pretty prohibitive. It remains to be seen, for instance, whether the United Arab Emirates has, and I believe, in a very open system of regulation with a lot of public input. There are those of us on the outside who have technical expertise and I think it's demonstrable, even in my own personal experience that when you provide input that the officials are listening to, that the system can be safer.

I'm not a fan of nuclear energy, obviously. But I do believe that we have these reactors and they should be operated as safely as possible while they are being operated. They are going to operate for a while. Spent fuel will need to be managed even if they all shut down tomorrow. So I believe in constructed, constructive engagement. I don't know to what extent the United Arab Emirates is developing a regulatory system and whether they have a regulatory system that will be open enough to allow public input. They have seen quite a bit of repression in the United Arab Emirates, they have seen quite a bit of instability politically, it has been repressed. I would recall for you, Commissioner that in the 1970s Iran was considered very suitable for massive nuclear energy development. After 1973, France, Germany and the United States encouraged that. Twenty reactors were planned; the reactor that was completed by (indistinct) recently, was originally started by Siemens. The French began a uranium enrichment programme. There was talk of making Iran the centre for plutonium reprocessing for the entire region. And this was in the mid-seventies. By 1979, this regime that was supposed to be very stable but which was known to be repressive disappeared. Suddenly, we are in the middle of nuclear crisis where we are trying to stop Iran from. I think these are the kinds of questions that we haven't thought through enough. If you look at the statement of the Gulf War Operation Council from 2006 about nuclear energy development, they point to Iran, they point to Israel saying they are – they don't have necessarily peaceful programmes. We are going to do it legally and so on. I even believe the Saudi foreign minister said something about Israel's original sin. I do think, not only my opinion but that of Mohamed ElBaradei also, when he was the Director General of the IAEA that 90 per cent of the development of nuclear energy in the recent – in the last 10 years, by countries that don't have it, is essentially to develop nuclear capability under legal means.

So I think United Arab Emirates will build and operate reactors, whether this is an omen for large-scale deployment or not, and whether it is desirable or not, I think is more questionable. I certainly would not point to it as a good example of what we are doing.

MR JACOBI: Can I bring you back to recent US reactor development (indistinct) and I am just interested in your views about, putting to one side, I think you identified issues of projections of electricity demand but do you see that there are other causes that have driven reactor cancellations in the United States in recent times?

DR MAKHIJANI: Yes. Well, the electricity demand is a reflection of the general way the economy works. So until 1973 efficiency was not a consideration. After 1973, efficiency became a very big consideration and then later on it got built in to energy policy in the United States. We had a lot of research and development, appliance standards that have been built in to the system. I don't believe that all of these things are really effectively worked in to electricity forecasts, which is why we constantly wind up with forecasts that are too high.

MR JACOBI: The Commission - - -

DR MAKHIJANI: They are one-sided biases.

MR JACOBI: Yes. The Commission has heard that a significant factor in the deployment of New Generation capacity generally in the United States has been wide spread low gas prices in the United States. And I'm just interested in understanding your view about the impact of gas on developments, including nuclear?

DR MAKHIJANI: Yes. I agree with that. I think low gas prices – gas prices have been very volatile but as somebody who has studied energy commodity prices, again for more than 40 years, I think if you look at it carefully, gas prices have never stayed very high, although there have been many panics around gas prices. In this country, at least, they have not closely followed oil prices and so the escalation in gas prices has been much lower and now of course gas prices are quite low. The development in wind technology in the last 10, 15 years have also been very dramatic and wind is also apart from subsidies, quite low in price, probably unsubsidised wind would be about 6 cents, or 7 cents depending on the location. Now solar energy on the utility scale is about the same. So when you put efficiency wind, solar and gas together it doesn't look like a very good picture.

The other thing to keep in mind is to connect with something that I said earlier, is if you look at the deployment times of all of these technologies, combined (indistinct) plants are about three years, wind farms about two years, utility scale solar about the same and commercial and residential in solar is a few months. And so it is much easier, more economical and smoother to integrate that in to short term energy projections than it is to do nuclear. So there is that additional factor of risk which is much lower with all of these technologies.

MR JACOBI: I think that might lead us to something that you have said – in the notes that you've sent us, that – and you express a view that the same amount of money can produce far greater CO_2 reductions with wind and solar energy than with nuclear. And I'm just interested in you explaining the rationale for that view?

DR MAKHIJANI: Well, the rationale for that view is comparatively solar and wind are cheaper per megawatt hour. So you say, in theory, solar, wind and nuclear are – if you have a completely nuclear economy or a completely solar economy, completely wind economy they're all at zero CO2 systems because you are operating everything. There are no direct CO2 emissions in the generation piece of it. So while the upstream operated with zero CO2 then you have a zero CO2 energy system. If you – so basically it's a question of what does it cost to get a zero CO2 megawatt hour and currently I referred you to the Lazard estimates of last year. But the Lazard estimates of last year in relation to solar are already obsolete. Today, if you take the statement of the CEO of First Solar at face value, you would be generating solar at about $60 a megawatt hour in a year or two. Today, the subsidised solar is very, very cheap in the United States but by my calculation unsubsidised utility scale solar is about $70 or $80 a megawatt hour.

The estimates for nuclear range from $90 to $135 a megawatt hour, that is on Wall Street. In practice, we are now running at more than the higher end of that cost in the United States. If you look at the proposal of, I believe, Florida Power and Light – I will send you a correction if necessary, in the email, but there is a proposal for a nuclear reactor construction (indistinct) time back to resume construction in Florida where the utility itself is putting forward a price of more than $160 a megawatt hour and this is before all these delays and cost escalations and so on. We are talking about single projects. Another way you could look at it is the financial risk and the deployability of nuclear, is we are talking about single projects, like the two reactor project that was proposed a few years ago in Florida that was more - capital cost was more than the entire market value of the company. So that's the reason that Wall Street doesn't want to finance it, one of the reasons that it's very difficult to build it. It takes government subsidies. You can easily finance solar and wind on the open market. You can raise money for it because people can calculate the dollars and cents pretty easily, it's not risky.

MR JACOBI: Can I just come back to the statement and one of the things that I wanted to pick up with it is that the Commission has heard evidence that comparison of LCOE is not enough to evaluate respective technologies and one has to go to the total system costs. I am just interested to understand whether any studies have been done, or you have been involved in any studies that have evaluated total system costs, comparing and contrasting a renewables strategy with solar and wind and perhaps some gas, with the nuclear option? Sorry, we have just lost the audio. I think we just lost the audio at our end. Sorry, Dr Makhijani.

DR MAKHIJANI: No problem.

COMMISSIONER: I think we're back.

MR JACOBI: Are we back.

DR MAKHIJANI: Can you hear me?

MR JACOBI: Yes, we can. Thank you.

DR MAKHIJANI: Can you hear me?

MR JACOBI: Yes.

DR MAKHIJANI: Okay. I actually – can I go?

COMMISSIONER: Yes.

DR MAKHIJANI: I have been doing – so I did an initial take on it in terms of the whole US energy system but that wasn't really – that was a sort of first level feasibility analysis, technical and economic. But since that time I have done a number of studies, most in detail in the state where I live, Maryland, where I have – I am trying to chart a course for renewable Maryland. Efficiency, renewable energy (indistinct) obviously reliability and affordability are very essential. So a few months ago, I completed just such a system cost estimate. Obviously when you are looking out 20, 30 years of a completely renewable system there are quite a few uncertainties but there are uncertainties in all sides. There are uncertainties in business as usual, petroleum costs, gas costs. I think there is far less uncertainty in wind and solar costs because we know what they are and we know they're not going to be more than what they are going to be in the near future. They are more likely to be less but they won't be more because there is no sort of technological uncertainty that would drive the costs higher.

When I looked at all of the costs, when we looked at current short term projected battery costs for storage, the current efficiency of electric cars, the current cost electrolytic hydrogen production using available technology and you put it all together in to a system where whenever you flip the switch, the lights will come on, I found the most probable outcome is that renewable system with adequate efficiency measures – now this is very important, if you don't do efficiency, the equation may not hold. But the room for efficiency in the United States, in Maryland at least, is now the Public Service Commission has said we can reduce electricity consumption by two per cent a year, going out in to the future. And we have been accomplishing one and a half per cent a year. So electricity consumption in Maryland and the United States has been going down, even though efficiency efforts are uneven. With these caveats, taking (indistinct) cost of efficiency, that is much higher than what we are currently incurring. My best estimate is that a fully renewable system, with a moderate – with a moderate amount of natural gas, about 90 per cent reduction in CO2 emissions would probably cost significantly less than if business as usual.

Now if we look more seriously at (indistinct) business as usual, any region Australia, Maryland, the northeast, the mid-Atlantic region doesn’t really have a business as usual option. Because if we do business as usual, I think most people would understand that we are looking at climate catastrophe. So when you say there is very severe costs associated with climate disruption, whatever word you want to use, if we do business as usual, I think there will be catastrophic, there is already some disruption going on. Leaving aside those costs, I think the direct costs are likely to be lower given where we are today technologically.

MR JACOBI: Perhaps if we can break that up in terms of the sorts of technologies that we would be required to reach the outcome that you have just described. In terms of the transformation of the electricity grid, what would be necessary in order to reach that particular outcome?

DR MAKHIJANI: Well, it depends on what kind of attributes. Generally I think it is agreed that we want a grid that's much more resilient than we have today. So that automatically means you have more micro grids, you have to have more distributary sources and you have to have centralised resources that are responsive to distributary resources, so one of the sort of fine print problems with nuclear energy is you know it's ramping rates are poor. It's a very poor complement, at least current technology with nuclear is a very poor complement to variable energy resources.

So if you want to go in the direction of redesigning a system, you have to decide, once you get above 30, 40, 50 per cent wind, sometimes you're going to get 100 per cent generation, this already happened in Germany, for example, or Spain, and then if you have inflexible resources on the grid like nuclear and coal you're going to have curtailment costs that are pretty severe. So if you look at the system you have to develop (a) a system in which all of the available resources are very flexible, so long as you're planning to deploy renewables that are more than 30, 40, 50 per cent of your total, that is solar and wind. I don't see any scenario in which we can get there with less than that, in a practical scenario.

So that means that we have to have a smart grid. We're headed to a smart grid anyway, an intelligent grid, which means you have to have a communication system in parallel with your power system, you have to have smart appliances, you have to have real time rates, you have to have different institutional structures. I think one of the biggest unresolved issues which will be resolved one way or another in the next few years, at least in the United States, there are very active discussions in New York, California, Hawaii, soon to begin in Maryland, about the institutional structure of how the wires are going to be funded and paid for, so that we have resources, like I have solar on my roof, am I paying my fair share for the wires that come to my house to sell and buy the electricity. I think that cost is actually variable, depending on how much solar there is deployed in a distributed manner, the more you have, the more costs you have to adjust.

We have to go to real times rates. If you go to real time rates the consumers and producers of electricity like me have to have real time information about the state of the grid. It can't be just the utility that has real time information about the state of the grid because I need to be able to adjust my consumption so I optimise my sort of utility in terms of costs of performance of my home electricity system. So I think you need demand response, you need automatic demand response, you need institutional changes, most of all what in New York is called reforming the energy vision.

There are extensive hearings and studies going on in New York state and California and it is actually very interesting in Hawaii because they have isolated grids and more difficult issues because of that. So they're not a technical issue, so they are sort of financial, institution - our distribution grid definitely needs to be much, much stronger than it is today.

MR JACOBI: In terms of, again coming back to the Maryland study that you undertook, in terms of technologies that are required to be integrated, what sort of technologies were required in terms of storage within that grid system?

DR MAKHIJANI: The storage technology that we considered were battery storage, either stationary or with electric vehicles. So vehicle to grid technology. Actually from a grid operational point of view those two are fairly interchangeable so it doesn't matter much, so long as you have the capacity. We have a large stand-by capacity of gas turbines. You have cheap electricity available with a lot of surplus wind and solar at times when demand is low and supply is high. You make electrolytic hydrogen with that. That's how you use some of that surplus.

You have issues of storage. Hydrogen storage is a very well understood technology, of course a widely used element in the chemical and petroleum industry. Actually hydrogen is stored at practically every large electric power plant for cooling for generators, including nuclear power plants. So local hydrogen storage for, you know, weeks or months. A week's supply is a well understood technology; long distance hydrogen not so much. So I think the structure that I used in allocating the costs was a structure where you would produce and use hydrogen locally and store it locally. That's a technology whose costs are reasonably well understood.

Gas turbines, of course, also use - as one last element in that. Today's gas turbines, it's not clear that they can operate on 100 per cent hydrogen. I think that can be done, it's sort of a near term technology development issue, but they could reliably operate for a long period probably on 40 per cent or hydrogen and the rest methane, so then the question is where are going to get that methane. We know how to make methane from hydrogen and carbon dioxide, it's very expensive, but I did take that into account even though because it's necessary to fill those few hours where you can't do demand response effectively where you don't really want to add so many batteries that the cost spirals out of control, and gas turbines are cheap enough. It's a kind of technology of last resort that you operate at a very low capacity factor. So it's a little bit similar to the existing system but with different fuels.

MR JACOBI: Just one more question on this topic before I come to SMRs. I am just interested, you referred to the costs of funding the transmission distribution system. In terms of the costs of funding, distributed hydrogen generation and those sorts of technologies, where do you see that the resources are going to come from to be able to do that?

DR MAKHIJANI: I think the resources generally in the United States come from the private sector. In a regulated system it's up to the Public Service Commission to make sure that the electricity system is reliable and the elements that are needed for that reliability are worked out, you know, from year to year and every three years both at the regulatory level - I don't know exactly how you organise it in Australia, but here we're organised in grids, so Maryland is part of the Pennsylvania, Jersey, Maryland grid, or the PJM system, and so the regional resources are coordinated on a regional - the supply of resources are coordinated on a regional basis, and that is now beginning to take into account storage. So for instance in PJM today you can build 10 megawatt hours of battery storage and cell regulation, frequency regulation services, to the PJM grid. You can do this today.

MR JACOBI: Do you see the economic drivers emerging now to, for example, fund hydrogen generation within the system, or where do you see those economic drivers going to emerge?

DR MAKHIJANI: If you're building variable solar resources, you know, there is going to be cheap electricity available. Presumably there is going to be a demand for hydrogen or the Public Service Commission will make sure that there is a demand for hydrogen by requiring them to be built, so basically, you know, you have to ensure the reliability of the system. Where do the resources come from for investment and transmission distribution today? The distribution side investments are mandated by the Public Service Commission. The transmission side investments are basically overseen by PJM and the Federal Energy Regulatory Commission which has jurisdiction over the interstate issues. So I imagine the hydrogen will fall into the same category, the distribution of hydrogen resources will fall under the Public Service Commission and interstate system will fall under the Federal Energy Regulatory Commission.

MR JACOBI: Can I just come to the topic of SMRs.

DR MAKHIJANI: Sure.

MR JACOBI: You have expressed a view in the note you have sent us that they simply shift rather than solve the essential economic issues.

DR MAKHIJANI: Right.

MR JACOBI: Could you explain that view.

DR MAKHIJANI: Yes. So my conclusion is basically, if you look at the report, basically based on a study of the industry documents themselves, including an analysis by the Tennessee Valley Authority which seeks to build an SMR. So the core idea of an SMR is that you have smaller reactors. Of course you lose the economies of scale, reactors are big because cost of materials goes according to surface area, and power production goes according to volume, and the larger the reactor the smaller the material needed per kilowatt. That is the theory and that is why there were small reactors in the fifties, they were proposed and we went to bigger reactors because they were cheaper, all other things being equal. So you go back to smaller reactors, the underlying technology will tell you that the costs per kilowatt, in terms of materials and labour, the number of wells you need per kilowatt, the amount of steel you need per kilowatt will all go up. The proposal is that all of these costs would be offset by assembly line manufacturing. So you won't have to set it up on site. And in theory it is a fair idea to evaluate and you ask what is the size of the assembly line you need? And who is going to create this assembly line and the required supply chain, the vessels and the pumps and valves and all of it? So if you look at what the Department of Energy has said, what the industry itself has said is that you can't – so you are really displacing the heavy capital cost upstream from the reactor sites.

So now you don't have – in theory, you don't have a long construction time at the site. You could do it in maybe three years but you have a very high capital cost and a very high risk upstream of that. So that is what I mean by you essentially displace the cost upstream, so now instead of having a 10 billion dollar problem, you have got a 50 or a 100 million dollar problem because to set up a supply chain for say 100 or 150 reactors a year, you need that scale of investment. By my backup, and admittedly back of the envelope calculation, you need a supply chain investment that is about the same order of kind of an assembly line for airbuses or (indistinct) So it's very, very huge. So who is going to make all of these orders that will cause some private party to make that investment in the assembly line? With airbuses we know they get advance orders of hundreds of aircraft and they set up their assembly lines. The answer to that question is, no one other than governments. So the proposals have been that the Department of Energy should order a bunch of reactors, doesn't matter if the initial reactors are very expensive, or that the Chinese should do it. Eventually, I think if such a thing comes about, the more likely outcome is the reactors will be made in China. And so the jobs advertisement would fail.

How you would handle such a system from a regulatory point of view is mysterious to me because when you have assembly lines, as I note in my paper, you have recalls. Today we have got an 11 million car recall, one of the most reputable companies from perhaps the most technologically reputable country in the world, Germany. What are we going to do if we have 2,000 assembly line reactors that are found to have a fault through design? By design I mean as not properly conceived, or through some cover up, like what happened with Volkswagen. How are we going to deal with it? Are we going to shut them down? Are we going to send them to the manufacturer? Are we going to – it's unclear. So I think the issues around small module reactors – I do grant that assembly line could offset all of the cost, it's possible. But I think the fine print of small module reactors is much, much more complicated economically and in terms of the risks and investments, than their performance have led you to believe. That's why they're not – I mean I think – at least two of the four companies that are embarked on it, are already not pursuing it in the United States. Fallen apart before anything was built.

MR JACOBI: Can I just deal with just one final aspect of your paper in the time that we have left and that is the question of carbon capture and sequestration. And I am just interested in your views about whether you think that that is likely to be – that is going back to your topic from the start, whether it is going to be one of the, all of the above, technologies that we ought consider?

DR MAKHIJANI: Well, I think – I have a more (indistinct) view about carbon capture than I do about nuclear. Nuclear, I don't recommend. It's an obsolete technology. We don't need it. We can do without it, it's very risky. So I'm pretty unequivocal about that. Nuclear fission. The nuclear fusion can't help with climate to anybody's crystal ball, at least to mine, we can't rely on it. So carbon capture, I think for coal-fired to imagine that we are going to apply it to coal-fired power plants and keep them operating for decades, I think is an impossible idea. The number of sites you need, the costs. We are having trouble – and the proof that all that carbon dioxide will stay underground in the volumes that we are talking about at the variety of sites we are likely to need, very difficult. I am not an expert in the area of this, as a caveat, but I have studied the interagency report that is referenced in my paper, and the costs of carbon sequestration are so high that if you are looking at dollars and cents in relation to coal-fired power plants alone, it is cheaper to replace them with solar and wind than it is to try to back fit in and continue coal mining, quite apart from all the external costs.

All that said, I do think that carbon capture technology in the broader sense, not from capturing the gas and injecting it in to the ground, has some value because I think – and IPCC raised this in their most recent report, eventually, probably sooner rather than later, we are going to be talking about removing already emitted CO2 from the atmosphere. So obviously in the broader sense we are talking about carbon capture, not in the sense from emission from a power plan but to undo the damage that we have already done. Now that arena is far broader and in some ways even more difficult but I think we will need to confront that. So I think we need to take a look at carbon capture. I pointed at a soil storage of carbon as one example. There are other examples. But I do think we need to look at carbon capture in a more creative way, but I don't think it's very useful for coal-fired power plants.

MR JACOBI: Perhaps just one follow on, putting coal to one side, what about its relationship and potential with gas?

DR MAKHIJANI: Yes, now gas is – combined cycle power plants are a different animal; a) because these types of power plants could have a longer life within a renewable system because they could be powered by hydrogen or renewable methane. You can change out the infrastructure in the fuel cells more easily, you are starting with natural gas, you could go to renewable methane or hydrogen. The amount of carbon dioxide per megawatt hour is much lower. My hesitation with – and the reason I hesitated before I finished my paper, I was going to – I sort of put it in and took it out. On balance, I thought it will take too many pages to explain myself, so I'm very glad you asked the question. On balance, I think we need to – I don't know the situation in Australia, because I haven't studied it but I think we have enough natural gas fired power plants in the United States. There is a lot of surplus capacity generally in country, certainly acknowledged, including by the EPA and Clean Power Plan. So I think we need to make most effective use of the resources we have and also start phasing out natural gas because we are going to have to phase out most natural gas use before 2020. It's a fossil fuel.

My hesitation about continued use of natural gas is because I believe, if you think the climate problem is a shorter term problem 20, 30, 40 years, rather than a 100, 200 year problem, which we used to think maybe 20 years ago then the methane (indistinct) problem, the gas production problem, the pipeline problem which is at least now under control empirically in terms of data in the United States and all the things that we know where we are headed is that the situation is much worse than we thought, in terms of warming and leakage. I am much more hesitant to advocate a path that would imply that we can continue operating these plants for the indefinite future. The EPA actually also said that in the Clean Power Plan when it said that new natural gas plants are not part of the best emission reduction technology. So that was a very interesting statement because it would operate for (indistinct) So I think I would – it would be salutary maybe and useful to develop some sequestration in combination with existing combined cycle plants and look at that investment. So far, all these things have not been very promising but given that we might need these things, that might be the best context in which to develop a power plant related sequestration technology.

COMMISSIONER: Dr Makhijani, thank you very much indeed.

DR MAKHIJANI: You are very welcome.

COMMISSIONER: We will adjourn now until 10.00.

DR MAKHIJANI: Thank you.

COMMISSIONER: Thank you.

ADJOURNED [8.50 AM]

RESUMED [10.02 AM]

COMMISSIONER: Thank you very much for joining us this morning. We are looking today at low carbon energy generation and we are particularly looking at options that might provide that now and in to the future. I am particularly interested in the vision of small module reactors and your smart development. So I wonder if you wouldn't mind, just going through that vision statement and perhaps some of the principles of the smart technology.

DR ZEE: Okay. Firstly, I would like to thank you for this opportunity to introduce (indistinct) that we have been developing for the last 10 years. My name is, as introduced, Kyun Zee from (indistinct) I have my talk today under five subtitles.

MR JACOBI: Yes.

DR ZEE: Firstly, I would like to go through some of the SMR, small module reactor, some of those small and medium size we (indistinct) and is general (indistinct) The second title, I would like to introduce smart development history and what (indistinct) for the smart development and licensing activities.

MR JACOBI: Dr Zee - - -

DR ZEE: I would like to (indistinct) introduce our – as far as I understand, certain Australia has some sort of inland need for energy and water, or you know electricity. So we, in that case, the plant (indistinct) is very important, so I would like to introduce some of the dry cooling options that we think for the inland deployment of SMR. And my fourth talk is on recent information on collaboration of smart projects and smart commercialisation.

MR JACOBI: Dr Zee, if I could just interrupt there? Could I bring us to – I think we have a slide, slide number 5.

DR ZEE: Yes.

MR JACOBI: And I am just wondering about whether you could explain where you think the market for small modular reactors that you are considering development, where you think that market might be?

DR ZEE: Okay. My market estimation, as you know there are vast potential demand, that is most prominent international or the government agencies and international prominent institute estimated that by 2050 about 500 to 1,000 units will be needed. For the most recent US (indistinct) report, that was published in 2013, they conservatively estimated around 18 gigawatt (indistinct) in year 2013. In other words, if it is a 100 megawatt plus SMR like smart, that is around 180 units to cope with this demand. Or something, a smaller units it will be over 200 units. So in that case, if we assume that one unit cost about 1 billion dollars for the (indistinct) construction cost, then that will be over 300 billion US dollars by year 2035. And most recent estimation by (indistinct) as far as I understand it, they are assuming it is about 400 million dollars by year 2035. So it is not exactly to be (indistinct) proven market estimation but the amount of market size, I predict here is (indistinct) is about 200 units to 250 units multiplied by one million dollars, that will give you around 300 million US dollars.

MR JACOBI: Yes. Can I just – that is the total market. Where is it in the market that you think SMRs might have a market opportunity?

DR ZEE: The market opportunity we are looking for is a (indistinct) area, south-eastern Asia countries, also support of Australia probably, hopefully. The inland side, also UK is looking for SMRs too. US and Canada market, Canada is also – they have – they require large amount of energy for remote area, for the mining areas. So we think that there are plenty of sites, a sizeable, strong market and demand exists for SMRs.

MR JACOBI: Yes. Can I just take us from there to deal with what you see are some of the challenges in terms of deploying SMRs? We have got a slide for this; I think this is slide number 6.

DR ZEE: Yes.

MR JACOBI: Just wondering whether you might address the Commission on what you think some of the challenges in terms of deploying SMRs are going to be?

DR ZEE: We think – I listed here two different challenges and hurdles for – one is technical challenge, the other one is commercial challenge for deployment of SMRs in general. As you know, by nature nuclear requires every (indistinct) technology should be proven before it is implemented, actually implemented. So there are many fancy ideas of new concept for SMRs, especially SMRs these days. But those technologies, if it is really implemented to the plant, SMR plant, that should be in advance – should be proved and that is a little bit (indistinct) second regulatory licensing, unclear regulatory licensing hurdles. That is you have to – those meet licensing requirement which may not exist at this moment. So for the new design technology or new and best technology, they have to prepare licensing (indistinct) first. So there are large risk for those advanced technologies for licensing aspects. Another one is in general modular construction. I'm not talking about component level mobilisation but if it is a unit mobilisation that some of the (indistinct) companies are taking, that require – they have some contradict with the current licensing (indistinct) licensing requirement. So that there is existing – there exist those licensing issues for the modular concept.

Second part on the commercial (indistinct) as you know by the economy of scale, small modular reactors inherently disadvantage in plant economics when compared with the large scale nuclear power plant. At the same time, SMRs should compete with the other energy sources like gas-fired, coal-fired and those conventional thermal plants.

MR JACOBI: Yes. Could I just stop you - - -

DR ZEE: So they - - -

MR JACOBI: - - - there Dr Zee.

DR ZEE: (indistinct) very important.

MR JACOBI: Sorry. Could I just interrupt there and just ask you, you mentioned the disadvantage as compared with larger scale commercial plants and I am just interested to understand about whether you think that that particular disadvantage in terms of scale can be overcome?

DR ZEE: Yes. We think it can be overcome, or at least we can close to the large-scale nuclear power plants. That has been addressed in the IAEA documentation on SMR, economic aspects of SMR. By multiple mass production of components and learning (indistinct) and (indistinct) of design and engineering. Those also we can short term the construction period so that those interest, that is compiling, doing the longer construction period can be used. But still there is a – we have to overcome those economy of scale – those economy of scale can be compensated partly, I will say partly, by if you think about transmission costs by locating these small modular reactors near the consumer site. And if you think about the savings in transmission, savings in power loss and by applying that diversifying the application usage (indistinct) like producing (indistinct) desalination, fresh waters, those will be the beneficial (indistinct) will improve your plant economy and thermal efficiency of the plant, even though it is a small unit. But in general, that commercial (indistinct) are talking about here is in general. We have disadvantage in economy, the plant economics comparing it with large-scale nuclear plant.

MR JACOBI: You mentioned mass manufacturing as something that has been identified with SMRs and the advantages that they might offer, and I am just interested to understand the extent to which there would need to be – or what are the scale of the sorts of orders that might be needed to begin to see effects or benefits associated with standardised manufacturing of large volumes of items?

DR ZEE: Yes, that is the mass production I am talking about for example, if you are installing one gigawatt with an SMR, with 100 megawatts you have .1 gigawatt size, that will require 10 units of (indistinct) like 100 megawatt (indistinct) And each 10 units will require eight steam generators and four small size pump, reactor cooler pumps, so if you multiply by 10, that will amount to 80 steam - small steam generators, 40 reactor cooler pump with a single verification and design and engineering component. The design engineering you can produce 80 units, 40 units of (indistinct) so that will actually lower the plant cost (indistinct) implement those (indistinct) costs. That has been addressed by the – in Westinghouse during the IAEA (indistinct) corporation work on SMR economics. They said more than 20 per cent will be saved if there is a mass production of certain components.

MR JACOBI: Can I just take you to slide 8, and I am just interested in understanding the sorts of applications to which the particular reactor that you are developing can be put?

DR ZEE: (indistinct)

MR JACOBI: Sorry. Could I just take you to slide – I think slide number 8?

DR ZEE: Eight. Yes.

MR JACOBI: Just hoping you could explain the sorts of applications to which the smart reactor that you are designing can be put?

DR ZEE: The smart reactor can be utilised for the – just for the electricity generation or a combination of electricity generation as well as desalination. Or it can produce electricity and also the hot water, so the plant itself is a 100 megawatt electric plus the thermal energy output from reactor is 330 megawatts. But if it is converted to electricity, the efficiency will be a while (indistinct) one third, so that is 100 megawatt (indistinct) Now if it is combined with the desalination plant, we utilise around 10 per cent of the heat source which is (indistinct) the waste heat plus some of the high quality steam from after high pressure turbine. So if in that case we can produce 40,000 tonne per day of water as well as about 90 megawatts electric, or electricity. If it is utilised for the (indistinct) heating and also electricity supply then we can produce around 615 gigajoule per hour of 85 degrees Celsius hot water to the consumer and also electricity about 80 megawatt (indistinct) Those population are listed here, 100,000 to 500,000 population is majorly based on Korean, foreign Korean consumption with electricity per capita and water consumption per capita.

We utilise - we consume around 400 litre per capita these days, slightly over that. I know that Australia is 650 something, about 1.5 times more water is consumed per capita by Australian people. Also electricity, I think are very close to ours. We utilise around 10,000 kilowatt an hour per capita. Australia similar, a little bit more than that I know. So as far as electricity is concerned, pretty close. If it is water you consume more than in average than Korean people do. So if it is 100,000, a city of 100,000 population, we require around 100 megawatts electric as well as water of 40,000.

MR JACOBI: I was just wondering whether we might go to the development history and the time frames in which this particular reactor has been developed and I was just hoping you might take us through that.

DR ZEE: Okay. Our SMART development dates back to 1997 when we first started the conceptual design and basic design. Year 20 - only year 2000, year 2002, we started a one-fifth scale, what we call SMART pilot plant. Instead of going through 330 megawatts class or 100 megawatts electric class large size, actual size restructured with a one-fifth scale. Right. From that development we tested some of the components, you know, steam generators, we produced prototypical steam generators and also reactor coolant pump and other major (indistinct) with a small size boost. Okay.

After that SMART-P development period we started our actual size which means a SMART 330 megawatts thermal (indistinct) which is 100 megawatt difference, it's current design. So we did spend around two and a half years of pre-engineering period and then we go for the three years of tender design approval project. So during that period we produced all the, you know, licensing documents. We verified some of the important technology that should be validated by executing separate (indistinct) test (indistinct) test and, you know, component test, blah, blah, blah.

But the problem was when we were doing standard design approval, in the middle of the standard design approval , Fukushima accident occurred. So there, you know, just after one year after the Fukushima accident our regulatory requirements was asking us to take some more additional actions or design improvement for the cost of Fukushima action items. So after we get standard design approval in year 2012 we immediately started design improvement and the cost of Fukushima action item implementation projects, and that project will end next coming February, next year. So we have almost completed all the additional test experiments and, you know, design rectification.

COMMISSIONER: That might be a very good time for us to look in a little more detail of what you have done since Fukushima. Perhaps you might like to walk us through the activities that were taken following the accident in your design, and perhaps starting at slide 15.

DR ZEE: Okay. The recent development activities immediately after the SDA approval, I mean standard design approval, was the first implementation of post-Fukushima action plan. Our government required around 22, as far as my memory is correct, 22 - over 20 additional design changes or back fitting of the existing large scale operating   PWRs in Korea. But some of them are not quite relevant to this SMR, like SMART like SMR. But some of them, I'll say five, six items, we were asked to improve even after the standard design approval. That was the full passive safety system, if it is a new SMR, they want to have some initial provisions for the SMART to cope with the Fukushima-like accident. There was some additional provisions for our past existing passive systems. Right.

So what they did was we designed and test for three years full passive safety systems in addition to the existing passive safety systems with the SMART and licensed by standard design. We add some more passive safety systems and we add some more provisions, for example, adding of the water and fuel provisions for the ECT tank which is already existing. So we add some additional water resource to them like that.

COMMISSIONER: Can we go to the next slide?

DR ZEE: That is design and test of a full passive safety system is undergone with requirement by the existing, our integral testable specifically designed and constructed for the SMART.

MR JACOBI: Dr Zee, perhaps could we go to slide 16.

DR ZEE: Yes.

COMMISSIONER: Perhaps you would walk us through each one of those particular activities that have been designed back into the SMART reactor.

DR ZEE: Okay. There is the safety SMART plant is, for example, a passive residual heat removal system, it is a 1T called a long-term (indistinct) and for the, you know (indistinct) removal after reactor is shut down, even without any electric source because it is passive, it utilised the natural circulation to remove the k heat from the reactor core. The k heat is dissipated to the steam generator and then our passive residual heat removal system works on steam generator. So there are only two closed room operating in natural circulation, primary site is also natural circulated without any pump or force of the circulation.

Secondary site, the passive residual heat removal system is also operating with natural circulation. So our design requires two different natural circulation (indistinct) and we believe that by many simulation and also through our testable with the actual height, one to one height design, we verify and validated our (indistinct) the heat (indistinct) steam, pure (indistinct) under emergency (indistinct) And that is what (indistinct) effectively (indistinct) as our design. There will be no concern about under these (indistinct) SV or accident occurs. Also we utilise hydrogen (indistinct) system, is also passive, so there will be no concern about local hydrogen exposure, even under there is a (indistinct) hydro (indistinct) produced. The other one is this containment and steel lined concrete (indistinct) containment is the (indistinct) is very large we design. So that even though there is a (indistinct) explosion, it can accommodate whole expanded volume of the steam inside the containment. That is also, we satisfied the (indistinct) EUR requirement where aircraft crash by terror, whatever reason, the aircraft is impact on the containment building, that will withstand the area impact.

The minimise fuel failure means that we simulated every design basis accident, that during all those design basis accident, the fuel and the reactor core is submerging under the (indistinct) coolant water. So that that is because our volume of (indistinct) comparing with the power ratio is very large, so that there are plenty of waters in there. The other one we minimise the penetration piping size under two inches which is in the pipe way that is a (indistinct) accident of loss of coolant by pipe breaking, the water will – the metacore will not be (indistinct) uncovered.

COMMISSIONER: Okay.

DR ZEE: So that no fear of failure is expected. As far as the (indistinct) covers the metacore, the heat removal is consistent, so that there will be no concerns about (indistinct)

MR JACOBI: In terms of - - -

DR ZEE: The other (indistinct)

MR JACOBI: In terms of the - - -

DR ZEE: (indistinct)

COMMISSIONER: In terms of the passive residual heat removal system, the period of grace, I think you have got another slide which gives us an estimate of the period of grace under the smart reactor in comparison to Fukishima? Perhaps you could walk us through that?

DR ZEE: Yes. Fukishima actually that the earthquake, after the earthquake (indistinct) earthquake (indistinct) successfully shut down. The problem was – their problem was there was a transmission line coming from the outside of the plant, Fukishima plant, that transmission power was toppled down and there what happened, the off site power loss. So that emergency diesel generator started but because of the slurry the emergency diesel generator was flooded and it died, it shut down. So the battery (indistinct) battery operated for – it lasted more than eight hours when eventually they lost every single bit of electricity to (indistinct) to remove the casings. So that the reactor was overheated and they released some out the over pressure protection system, like a valve is opened and they release the steam, high pressure hot steam to the confinement building which is not containment building. This is just a panel of steel panels and there was a hydrogen explosion. On the other hand, smart even though the scenario (indistinct) is lost, blackout, our (indistinct) our system, automatic cooling starts because it's a fail system. So the (indistinct) in (indistinct) case closed position and if electricity is out, it will open the circuit and our (indistinct) system as you know is a passive, natural – by natural circulation. It removes the (indistinct) from the reactor core to (indistinct) generator, steam generator to (indistinct)

So our core (indistinct) ability is maintained for three weeks. If (indistinct) is properly filled with water, or even the water is dry out, we think about the air-cooling of the ECT, heat exchange, so that we can maintain the core status as required. The – normally – the every requirement on the passive system is you have to (indistinct) time (indistinct) grace time means that the time that required without any operator action. They require (indistinct) about 72 hours but the smart, if it is more than three weeks, I think it is – we can (indistinct) because we have separate provisions to supply water to the ECT (indistinct) of the (indistinct) RS system. And there will be plenty of time to cope with the – any accident, even severe accident event.

COMMISSIONER: Thank you.

DR ZEE: (indistinct)

MR JACOBI: Can I take us back – I am interested in understanding the extent to which prototypes or the particular technologies being integrated to be tested? That is, I am interested in understanding how far the particular technology has been demonstrated or tested and I think perhaps that might bring us back to slide 10.

DR ZEE: From (indistinct) yes. Okay, technology validation. If you – please refer to page 12 - - -

MR JACOBI: Sorry.

DR ZEE: Okay. In parallel with the standard design activities on the right hand side, (indistinct) design and engineering activities, they produce design better. And then that should be verified and validated. Also those design tools should be verified and validated. So what we did was we (indistinct) what they call (indistinct) which is most important for the verification and validation for safety system validation. That is the normal way. We brang the sequence of accident or operational procedures, so that by that we can table – we selected the most major test activity for experiments that we have to validate and verify. The verification of two is also done during that SDA period, so these codes, computer code system, utilised for the design and analysis activities all should be verified and validated with the safety test and separate prep test.

So a safety test is majorly required for the safe system, right, and the performance test is required to verify the performance based design. So there are two different tests and experiments at the same time we have to show it to our regulatory body that our design actually is correct and accurate so that it can be utilised for the standard design. Also, our system design tool should be verified by separate different tests and all those either for (indistinct) test.

So safety tests are listed. Major safety tests we've done are listed here. On the right-hand side, those performance tests are listed there. But as you know, the response reactor has been - the history of development is 1997 we started. So there are many different tests and experiments. If we add all these, they will amount to 15. So instead of these 22 that was performed during the safety of our standard design (indistinct)

MR JACOBI: I'm interested within Korea have you developed a demonstration plant or how much of the particular technology has been demonstrated?

DR ZEE: Normally reference plant or the first ever kind plant should be - you know, that is a normal - until now, when the US Westinghouse built their first AP1000 unit in China, right, my personal opinion is that because smart - even though we adopted some of the innovative concepts and systems, it is basically based on the already proven pressurised water reactive technology. So cool vapour is where the technology base is based on current operating (indistinct) technology. So what we did was we did some - if it is innovative or an innovative concept like a steam generator that has not been utilised in a commercial basis. We test in Montreal. Through Montreal we tested the performance of the helical coil steam generators. We tested those in services (indistinct) tools that will be utilised during the reactor operation for the helical coil steam generator tubes.

So those things were done by separate different tests and component tests, right. All of the hydraulic safety system tests was done with the scale bar of 1.8 with the ATR. That is over $US 20 million we invested to build that testing and as a reference I think the first ever kind SMART unit 1 and 2 will be built and operated in Saudi Arabia first. So I think combining all these separate impact tests, component tests and performance tests and infrastructure tests plus actual plant, that will verify and confirm the associated technology we implemented into the SMART plant.

MR JACOBI: Can I come now to the design approval and I'm just interested in that I understand that the SMART has received zone approval in Korea.

DR ZEE: Yes.

MR JACOBI: The Commission has heard about the effects of design approvals outside jurisdictions and I'm just interested to understand the extent to which the design approval for this plant in Korea might assist its licensing in other jurisdictions.

DR ZEE: That is a difficult - I think Australia, if you are going for nuclear power you will definitely have a regulator because you have already the research reactors in operation.

MR JACOBI: Sorry, can I interrupt.

DR ZEE: Sure.

MR JACOBI: I'm not so much interested in Australia. I'm interested to understand the effect of if one obtains a design approval in Korea, does that mean that that would assist the licensing in the United Stated or in Europe?

DR ZEE: We believe that the Korean regulatory (indistinct) reactor requirements are equivalent to the USNRC's, the US requirement, because our regulatory system is majorly based on the US regulatory system and all the technical requirements can be one-to-one match to the NRC's, you know, Red Guide or the regulation of - what was it - standard. So that is we think we are very much compatible with our regulatory system - compatibility of our regulatory system. But as for your question do you accept it or not, I cannot say to you immediately but for our PPE agreement with the Kingdom of Saudi Arabia we agreed to follow Korean regulatory requirements.

MR JACOBI: Can I come now to deal with that arrangement. I'm just interested, first of all, in dealing with the project time frame and I think that slide 19 - - -

DR ZEE: Yes, the project time line. I listed in here until we achieve the construction permit, assuming that we have a two-step licensing - the first step for a construction permit and the second step for the operation licence - until the CP, construction permit, we think it will be around four years. That will include the science arrangements and the documentation for CP application and also licensing review of two years. That is normal. We, in Korea, a licensing review period is about two years for the preliminary safety analysis report for the construction permit. After the CP is issued, we think four years. If it a (indistinct) plant, it will take around four years of actual erection, system implementation and construction of the buildings and the last one year is on the initiating tests, start-up tests. So that will give you five years plus three years plus one year of site arrangements, that will give you a total of nine years, conservatively I think.

DR KIM: And it is very conservative.

DR ZEE: It is very conservative. What we say the final goal once it leaves the - after three, four units of construction, we expect that from the first concrete of main building to the COD, which is the completion date - commercial operation date - we think it will be three to four years.

MR JACOBI: Do you have a view as to the sorts of time frames that you expect on nth of the kind build overall?

DR ZEE: Yes, by - - -

MR JACOBI: How much - by what sort of period of time do you think that the nine years might be reduced?

DR ZEE: So once you have a site we think that the environmental report (indistinct) that, you have to collect, if the site is available, potential site is there and we have to collect all those geological data and, you know, meteorological data, you require around two years. But what I am saying here, 12 months, a one-year period is, assuming that you have a potential site, candidate site, and assuming that those datas are available, and what I'm saying here is we have to prepare - if it is a - I don't know, if it is a seashore site much easier. I mean, you have a very accessible (indistinct) is there, but if it is an inland site with transportation of heavy equipment you need to figure it out. You have the ground, you have to dig. That will give you approximately one - I think a 12-month period for the site arrangements. So normally in Korea we do it at the same time.

So until the CP, it takes about two to three years in Korea because already they are managing the site area and they, you know, collect all those potential sites, meteorological data and geological data and everything. What we did with Kingdom of Saudi Arabia is we utilised first abounding site values, assuming what we call generic site values, right. Then we will correct or optimise later on, once the site is completely fixed then we will back feed the site data and check whether our engineering data is within that boundary, that site (indistinct) in our. By doing that we can, you know, sometimes take some of the disadvantage in economy side, it will increase because the plant is not only optomised for the site. But still we have reduced the construction period by doing that. That's my general concept of the site preparation.

MR JACOBI: Can I come now to deal with the arrangement that KARI has entered into with the Kingdom of Saudi Arabia, and I think perhaps if we can pick up from about slide 27. I understand that an agreement has been entered into because - sorry, slide 29, that an agreement has been entered into between KARI and Saudi Arabia with respect to planning construction. I am just wondering whether you could explain that.

DR ZEE: Okay. The pre-project engineering agreement is the first implementation - first stage implementation of our government to government MOU or SMART partnership. It is during that PPE agreement we will do first of a kind engineering specifically designed into the Saudi environment. Okay. Because there the plant cooling options should be the dry cooling options, if it is the inland site near the consumer site we need to prepare a water resource even though it is not a huge resource but we need to have some additional water resources so that it can - we need to optimise the balance of plant site because the ambient temperature and plant cooling is different from the current standard design ,and also we need to - even though the test of our full passive safety system is there, we have to add onto the standard design approval, design features, plus those additional post-Fukushima actions items.

So those are the important areas for the SMART units 1 and 2. During that period they wanted to participate in the SMART nuclear steam system design, right, which normally KARI is performing. So by CRT, OJT and OJP for two and a half years we will repost more than 30 Saudi engineers to KARI site design centres and we will, you know, give them training, starting from the general training to the specialist job Korean team training and we will have them participate in selected parts of the design activities together with the KARI engineers and scientists and whilst that - we will prepare the supply proportion for the SMART units 1 and 2.

That was the first part in the PPE agreement as well as the government to government MOU. So all these activities will be done within a three-year period together with the government, the KA CARE which is a Saudi government agency.

MR JACOBI: Do you have a view as to the time frame, assuming there was a decision to proceed, the sort of time frames that will be involved in potential construction before any potential operation of those plants?

DR ZEE: So the previous slide, starting from 1 December this year, our PPE will last three years and then at the end of November in year 2018, then we think that about six months to a year for the construction, preparation of construction in Saudi Arabia and, as I indicated, about five years will last for the actual construction and operation for first one and two units in Saudi. So that's the current agreed time schedule with the Saudi side.

MR JACOBI: You referred to some modifications to the cooling system for a potential inland site.

DR ZEE: Yes.

MR JACOBI: I am just interested, you might be explain the implications or first the technical nature of dry cooling and then the potential implications of that for the operation of the plant. I think slide 25 might be helpful.

DR ZEE: Yes. We studied some of the - whether we can deploy SMART's reactor and SMART's plant in inland sites. Inland, I mean if you have plenty of water source plant cooling is no problem, like if you have a large, you know, river or lake, then you can utilise those secondary water for measured cooling. But if you don't have, we searched many different cases of thermal plant which is operating in (indistinct) area and some Utah and New Mexico in the US where the water resource is sparse. We are utilising some of the dry cooling, bad cooling, sort of.

But what we did here is we searched how large or how we can design the back pressure of the condenser because normally when there is a back pressure is very important for your secondary site efficiency, plant efficiency. So by properly adjusting those design requirement as for the condenser site and these dry (indistinct) units, we think that we can have a proper plant cooling. Our conclusion was that indirect dry cooling which is not direct cool be – the turbine condensers but we will have – because it is a – in case there is a (indistinct) holes or any (indistinct) or failure in the condenser site, we do not want to pass over any small amount of radioactive material through condenser to the atmosphere. So we selected – even though we sacrifice some of the fuel of the thermal efficiency, I think indirect cycle will be proper. So that is the improved indirect dry cooling. Depending upon your site conditions, if the ambient temperature is very high, you may require some of these (indistinct) temporary (indistinct) to the fan cooling to maintain the condenser temperature evaporation.

MR JACOBI: The slide refers to there being power loss, or in effect – and I think you have referred to there being thermal efficiency loss. What is the extent of the thermal efficiency loss estimated to be for dry cooling?

DR ZEE: Dry power loss, we estimated that would be around seven megawatts (indistinct) to cool down the (indistinct) plant and also the in-house – other in-house load will be around five megawatts, so total of 12 megawatts will be gone – will be lost if you apply these dry cooling units. And then we think that (indistinct) megawatts electric is normally it will be 103 megawatts electric but it will be changed depending upon the plant design for the actual site. Could be 95 to 100 that is my estimation of what will be the actual electricity to the grid. So if you search for the reference, there is around 12 per cent downgrade of your electricity to grid. Nominal value. That is because your in-house load is increased due to (indistinct) and secondly, your back pressure is a little bit higher than the sea water cooling, so that your thermal efficiency is degraded, so that your electricity to the grid, actual grid, you will lose around 10 to 15 per cent and that is what the normal (indistinct) are estimated. But in this case, we'll lose about 12 per cent.

MR JACOBI: And I think perhaps one last question, with respect to that, to what extent is that particular dry cooling technique, or plant, been tested with your smart system?

DR ZEE: To me, I think there are many thermal plants. We already utilise this in direct – direct dry cooling for the thermal power plant. So that condenser site (indistinct) is totally different from the primary site, nuclear (indistinct) Secondary cooling, secondary site cooling and it doesn't matter whether (indistinct) say thermal plant or it's a nuclear plant. There exists already technology and already thermal plant up to even 500 megawatt electric plus. Thermal plant is equipped with these dry cooling, fan cooling units. Of course, 100 megawatt, 400 megawatt (indistinct) in China, in (indistinct) in the US they utilise some of the dry cooling units for the plant condenser (indistinct) So I think there will be no technique (indistinct) for these dry cooling units. Why then they did not utilise this dry cooling for the nuclear plant because nuclear plant if there is a 1,000 megawatt electric class, the water resources (indistinct) is enormous so we cannot utilise this dry cooling. But I think for the smart – for SMRs we can (indistinct) this dry cooling units if it is in that site.

COMMISSIONER: Do you have a view about the increase in costs with the dry cool?

DR ZEE: Yes, I think it will be increased, I mean (indistinct) cost – construction cost will increase (indistinct) is dry cooling units because you need initial unit for the – you may require some of the certain cooling towers, the chimneys to increase the air cooling capacity and also – but still there is a advantage and disadvantage. Even though it is a (indistinct) plant in the huge pump house for the secondary cooling, you need protection walls that goes to the (indistinct) 100 millimetres large structure, waves protection structure. So – but still we estimate about 15 to 20 per cent increase (indistinct) inland site because you need to pay additional transportation of everything and additional (indistinct) for this dry cooling units and so on. So we estimate about 20 per cent of (indistinct)

MR JACOBI: Just one last matter, I'm just interested in the extent to which it's possible to ramp this particular plant, or the extent to which this plant might be able to follow load demand?

DR ZEE: I'm sorry, the connection is (indistinct) we lost (indistinct)

MR JACOBI: I'll try again.

DR ZEE: Okay. What was your last question?

MR JACOBI: I'm just interested to understand the extent to which this plant can be ramped or it's capable of following load?

DR ZEE: You mean the (indistinct)

MR JACOBI: No, sorry. I will take a step back. The Commission has heard that some plants have the capability of following load, that is peaking style plant such as combined cycle gas turbines and I am just interested in understanding the extent to which this particular nuclear plant can follow the load, or follow demand from the grid.

DR ZEE: You mean the grid?

MR JACOBI: Yes.

DR ZEE: You mean load following capability?

MR JACOBI: Yes.

DR ZEE: Okay. Well, load following capability, I think we can cope with conventional load following and even if it is a – be normally - - -

MR JACOBI: Connection has failed.

DR ZEE: We've done several different scenarios of load following. We haven't done frankly speaking, the frequency control of load following but we think that these smart reactor can cope with a daily load following that conventional reactors. We have a very wide operation range because this reactor the – was designed to - with a wide operation base as a ORSD, we have a (indistinct) margins. The solo margin is rather large. Larger than the (indistinct) so that, you know, range of (indistinct) is wider, okay? So we can move around. Even though it is not good for the reactor, for the nuclear plant, I think we have more flexibility than the larger, to be honest. In fact the height - the core effective height is about two metres, so the actual (indistinct) oscillation is not - naturally there is no actual (indistinct) all right?

All that stuff, I mean, all the margins, the wide operation range, it will cope with both followings much easier than the conventional (indistinct) we get done in our 12, 6, 12 (indistinct) 242 (indistinct) so they are - I think technically it is very compatible with - to deal with. Those are very small problems.

COMMISSIONER: Gentlemen, thank you very much for joining us this morning. we very much appreciate your time and your evidence. We'll now convene again at 12.00. Thank you.

ADJOURNED **[11.12 am]**

RESUMED **[12.01 pm]**

COMMISSIONER: We reconvene at 12.00, and I welcome Ms Tania Constable and Prof Peter Cook. Mr Jacobi?

MR JACOBI: Tania Constable is the CEO of CO2CRC and a senior fellow of the University of Melbourne. Tania has had an extensive career in the Australian Public Service, most recently with the Commonwealth treasury, and prior to that - prior to her time at the treasury, she worked in the field of resources and energy over the last 17 years. Most recently Tania was the head of resources where she had responsibility for policy and legislative advice to the Minister for Resources and Energy on oil and gas regulation, exploration and development, mining activities for coal, minerals, and uranium.

In 2013 Tania was recognised with an Australia Day meritorious award, public service medal for outstanding public service in the development of Australia's liquefied natural gas, and other resources in the energy industries. Professor Cook is one of Australia's foremost scientists and technology leaders in the areas of energy, greenhouse technology, and sustainability. He is a professorial fellow at the University of Melbourne, a company director, consultant, senior adviser and author. He was an IPCC coordinating lead author, and in this role was a co-recipient of the Nobel Peace Prize for 2007.

He has been a consultant adviser on resource and energy issues in Australia, Finland, Greece and other countries. He's been a consultant to NASA and various national governments and a range of companies and other boards. He's occupied a number of senior executive positions during his career. In 2003, following five years as the executive director of the Petroleum Cooperative Research Centre, he initiated the Cooperative Research Centre for Greenhouse Gas Technology, CO2CRC, and served as its chief executive until 2011, and continues with CO2CRC as a principle adviser. The Commission calls Ms Constable and Prof Cook.

COMMISSIONER: Professor, if I might start with you in the broad, we've been hearing evidence over the last couple of weeks about climate change. I'm interested in your view about how we're doing globally, and then to bring that back to Australia. I'm particularly interested in your view about that, the achieveability of 450 parts per million. Then we'll move across to the subject that we've asked you to talk about, which is carbon capture and storage.

PROF COOK: Well, first of all let me say I'm not a climate scientist. It's one of the things that I've been interested in, that I'm published on, but I am not an expert in climate science. So I generally go on what I read, if you like, from people who I regard highly. The issue very often boils down to, well, is the jury out or is it in? Do we believe it?

Well, my view is that you never get 100 per cent certainty on anything in science, so if people are saying, "Well, there's just a slight uncertainty," that's not the basis for taking no action, in my view. I think that the cautionary principle does apply, and I think it's appropriate to take action. Are we going to get to 450? Not the way we're going we're not. I don't think there's quite the sense of urgency at the moment.

People pay lip service to these things, but if we take carbon capture and storage, and Tania will talk about this much more than I will, we're not actually seeing the action that's needed by industry and so on if we're going to actually get where we want to get to. So I think it is achievable. Is it achievable with what we're doing at the moment? Probably not.

Should we be achieving it? Yes, we probably should aim at that. Are we certain that its going to - 450 will cool two degrees? No, we're not. You know, there's some leeway there, and there is more science to be done, but that's no basis for saying, "Let's do nothing until we know for sure."

MS CONSTABLE: Am I able to add to that, Commissioner?

COMMISSIONER: Certainly.

MS CONSTABLE: So the 450 parts per million, which is equivalent to a two degree scenario, and that work has been viewed quite extensively in various reports by the intergovernmental panel on climate change by governments around the world, by the IEA who look at it quite - in similar terms, the IEA are 450 parts per million, the IPCC talks about the two degree scenario. Peter said it's difficult, but that's the scenario that we need to work with in a portfolio approach where carbon - technology such as carbon capture and storage is going to be needed, otherwise the costs are going to be so much higher.

The two degree scenario, governments have already started to talk about, well, is it appropriate to talk about 450 parts per million, two degrees. Is a reality more likely to be four degrees, or even six degrees? If we start to move down that track and have those sorts of discussions, then based on what the climate scientists are already saying, that's very difficult for us.

So no matter what, it doesn't matter whether it's four degrees or whether it's two degrees, we need to do as much as we possibly can in a global situation with all of the economies at the table, which is what Paris brings with the climate change negotiations, to actually make sure that the commitments are in place across the world to actually achieve significant cuts in omissions. Australia is well placed to do that. Well, we put commitments on the table out to 2020. The government of the day has already made a commitment that they will look at what the commitments might be post that 2020 period.

PROF COOK: Perhaps I can just add to that, in saying that I don't think we're on track to reach the 450, I'm talking globally. I'm not talking about in Australia. I'm talking globally.

COMMISSIONER: Well, let's talk about Australia.

MS CONSTABLE: Well, Australia has put forward commitments out to 2020, based on to a 2005 position. Certainly we're on track to meet those commitments out to 2020. I think the real problem starts to occur, the real challenge rather than problem, is what does that look like after that? It is going to take not just one government, but governments across Australia to come to the table and agree what those post 2020 targets might look like, and how we're going to achieve those in the economy across all of the different economic sectors.

So it's not just a matter of the power sector. It will involve all industrial sectors. So this is an issue for all governments, industry, and research communities to work together to make sure that we are able to achieve significant cuts in de-carbonising the economy across all of those sectors. I think that what we're doing places us well to participate in that debate.

COMMISSIONER: I think that's probably the right time for us to get into your sector. I mean, we are looking at all the technologies that might be applicable, and clearly nuclear is one. Carbon capture and storage is another. If I go to the IPCC special report, and the summary of the policy makers, which I think you participated in, Prof Cook.

PROF COOK: That's right.

COMMISSIONER: I read one of the conclusions, and I'd like to understand the basis for the conclusions. It was, "Carbon dioxide capture and storage technologies could reduce lifecycle greenhouse gas emissions for fossil fuel power plants," and then the bit that interests me is, "Medium evidence, medium agreement".

PROF COOK: Sorry, "medium" - - -

COMMISSIONER: I know it was a long time - - -

PROF COOK: Yes, that's right. Where are we now? "Medium evidence, medium agreement," that's - - -

COMMISSIONER: Am I reading too much into that?

PROF COOK: It's just the very formalised process of the IPCC which - - -

COMMISSIONER: Could you explain to me that part of it and your view of it, more importantly.

PROF COOK: I think that this is the most recent one. I was involved - I don't think this is the special report, is it?

MS CONSTABLE: Yes, it is.

COMMISSIONER: It is.

PROF COOK: This is the most recent one, isn't it?

COMMISSIONER: Yes.

PROF COOK: That's right. I was involved in the previous one, not in this one. So in terms of the precise words that are here, I'm not responsible for them. What they mean, I mean basically "limited evidence", they were not able to get a lot of peer reviewed literature because they don't try and collect new information, they go on peer reviewed literature totally. So what they're saying is they need more evidence. Medium agreement is what it says. There was not universal agreement on this. There was obviously enough agreement to say the weight of evidence would suggest this, but they're not saying here that everybody agreed with that. So that's to do with (indistinct)

COMMISSIONER: In that case let's step back a bit and just talk about the technology itself and where we are, and particularly to perhaps start it on your point in terms of power generation and that being the biggest greenhouse gas emission pollutant to date. I think you've got your second slide which talks about world energy consumption (indistinct) for that. Perhaps you can walk us through this particular slide.

MS CONSTABLE: I included this particular slide because really what it sets here is the scene for a whole range of challenges we have at a global level around energy. So the story here is that this is really an Asian story. So where are we going to see energy consumption at a global level going forward? Most of that is going to occur in the Asian region. So China is currently putting in one coal-fired power station every 10 days. India, between 2015 and 2018, is putting in 178 new coal-fired power stations. The Asian region in terms of LNG is consuming a considerable amount of LNG during this period. So where are we going to see the increase in energy over that period? It will be in the non-OECD areas and in that Asian region.

So the coal capacity in 2015 - just to give you an indication - we're seeing 867 gigawatts in China, 246 gigawatts in India. How does that compare to Australia? 37 gigawatts. By 2040 alone, India will be expected to add about 342 gigawatts of coal capacity. So it's a huge amount of energy demand coming forward. What does that mean for Australia? As a commodity producer, a big fossil fuels producer, and a supplier to that Asian region, it's in our interest, given that in 2014 alone our exports on fossil fuels were $68 billion. Now, that's a huge amount for Australia. We can't afford not to be in this debate, not to take it seriously and not to have the likes of carbon capture and storage as part of a portfolio of solutions on technologies, Commissioner, because that would be (1) irresponsible, but (2) I want to make this very clear and it’s one of the key messages I actually would like to leave the Commission with, this is not a competition. In terms of looking at this whole issue of emissions reduction and energy security, those two – that nexus, in the longer term, we need to make sure that we have a portfolio of technology options available around that 2030 to 2040 period, to be able to really meet those two particular goals at the same time. Which is not going to be easy to do, I must say.

COMMISSIONER: Not based upon those projections - - -

MS CONSTABLE: That is exactly right.

COMMISSIONER: - - - requirements.

MS CONSTABLE: Yes.

COMMISSIONER: Because if we understand some of the technical literature they are looking to be CHC free by 2050 – within the two degree limit that have been established. So that is going to take a number of technologies to be able to do that.

MS CONSTABLE: Exactly. And I think that from the perspective of the use of fossil fuels over that time, it is unrealistic given the numbers that I have just talked about and what is going in to China, what is going in to India, for that to – for anyone to say to some of those economies, you are not going to draw coal out of the ground, you are not going to draw LNG out of the ground. It’s unrealistic and it’s not something that is going to be possible. So we need to make sure that those portfolio of options are there to be able to address the needs that the world economy has.

COMMISSIONER: When we look at the global emissions reduction effort to date and get a sense of what is being achieved and what is likely to be achieved?

MS CONSTABLE: So we thought it was important to put this up and just talk about the global effort on energy. This is the second goal that needs to be considered in the reduction over all of those global emissions. And this looks out of course at who is contributing what at a period – we're looking out to 2030, 2040, 2050. Most notably of course, the renewables is playing a big part in terms of contributing to that global emissions reduction ethic. We have seen an incredible increase in the use of renewables which is a great thing. We are also seeing some emissions reductions through fuel switching. Importantly for us, and we are talking about carbon capture and storage of course, is that 17 per cent of the overall global emissions effort, when you are talking about the scenarios we started off with in the climate debate, 17 per cent of that global emissions reduction will need to come from carbon capture and storage to achieve that overall goal. Now we are on track. Even though it is viewed that carbon capture and storage is moving slowly, at a global level, we have got to remember that we are talking very big capital investments, much bigger than we have got on some of the renewables technology. So it is going to move more slowly because of the different aspects of carbon capture and storage but we do see a lot of that effort starting.

We have got first of a kind starting to occur across a range of industrial processes, not least of all in Australia very shortly with Gorgon which talk about that later on. And we have had Boundary Dam in Canada, around brown coal and we will also talk about that. But around that 2030 period we will see more and more projects coming on line at that global level. There is 55 projects at various stages of planning and these are figures that the Global Carbon Capture and Storage Institute, which is located in Australia in Melbourne, they have a very good understanding at that global level of projects around carbon capture and storage. So from the development stage right through to the execution stage, there is 55 projects in various industrial areas that are in the planning stages.

MR JACOBI: Could I just bring us – perhaps take us a step back and go to the currently mature technologies with respect to carbon capture and storage, and perhaps we will come later to the concept in development. I am just wondering whether you could offer a brief explanation of the broad concepts of the technologies that are involved and I think we have got a slide for this, and it might be slide 6.

MS CONSTABLE: So we will go through some of those technologies. I am going to get Peter to take you through the expert around, from a technical perspective, around the carbon capture technologies, pre-combustion technologies, post-combustion and what that means, oxy-fuel, all of which we have been working on in Australia and then the storage, which is quite exciting. I have done a lot of work on site characterisation around Australia and specifically for the CO2, CRC we have the Otway site which is near – in

Victoria and we want to talk about that, if that is all right. Get Peter to take you through the various capture technologies if that's okay.

PROF COOK: If we turn over the page and look at six, the three main options, the pre-combustion, post-combustion, oxy-fuel capture and this is all about producing as pure a stream of CO2 as you can get. The reason you are doing that is because you don't want to be putting lots of oxygen in the ground or lots of nitrogen in the ground. So what you are trying to do is get something that is fairly pure and it ranges up to, from fairly pure to very pure. Pre-combustion capture is all about separating out the carbon and the hydrogen from coal in the first instance. And so you end up there, essentially with hydrogen as your fuel and carbon dioxide, quite a pure carbon dioxide. And it's a process called integrated gasification combined cycle. What that is about is a chemical process essentially. You are then able to use the hydrogen as a fuel, or you are able to directly – for electricity generation, or you are able to use the hydrogen for vehicles or whatever else you want to do with it. There are people looking at this on a large scale. Is this possible at a large scale? It's being done on a small scale and it's being done commercially but primarily for chemical plants and the like. So it's a tried and true process but it's not tried and true in terms of massive scale you need to do it at for power generation, at the moment. But it is being looked at. There is a company doing it in the United States, place called Campbell County which is in the southern United States and I think we might have something on that there.

Post-combustion capture is the more normal process that applies. You are burning a coal, you end up with a blue which has about maybe 10 per cent CO2, sometimes less, a little bit more, depends on the efficiency of the plant. You have then got to get that up to about 90 per cent, so you are able to do that by putting it through various solvents and (indistinct) membranes. There is a variety of ways you can do this, so what you are doing is you are stripping out this relatively dilute stream of CO2 and making it in to a concentrated stream of CO2. That costs money to do that because you're using solvents and you have to heat those solvents and get the CO2 out of it and so on. I am happy to go in to the detail of how you do that but I am just trying to give you the big picture at the moment.

MR JACOBI: Big picture would be good.

PROF COOK: The other one is oxy-fuel combustion and that is where you are actually burning the fuel, not the air and of course air is 80 per cent nitrogen and that has no – you are not burning nitrogen or anything else, it just goes through your flu stream and just a darn nuisance. So what you are doing, you are actually getting pure CO2 in the first instance which you are getting out of the air and that costs you money. But then you are burning your coal in a pure stream of CO2 which means you – sorry, a pure stream of oxygen and you then get a pure CO2 out the other end, plus your power. Now that has been tried very successfully in Australia through what is called the Callide Project and they got a very pure stream of CO2 out of – essentially no problems with that. The problem is always cost with these things. You know these things do cost money but in terms of knowing how to do it, all three of these processes have been done at a variety of scales and so we know they work. It's a matter of making them work economically.

MR JACOBI: Could I just come to the issue of cost? At the time that the 2005 report was written, I notice that there is a reference to hope that the cost of capture, which I understand is the most expensive part of CCS technology, that is the capturing of the CO2, could be reduced by 20 to 30 per cent. That was a view that was expressed in 2005 over the next decade. I am just interested to understand whether or not advances have been made in making it more economic since that time?

PROF COOK: Yes. But not to the extent that we anticipated in 2005 and the reason for that is that it hasn't been undertaken at the – with the number of projects that we anticipated in 2005. It has come on more slowly. We believe doing this, we are actually getting on and doing it, it's an essential part of bringing down the cost. If you look at the Canadian example, the Boundary Dam where they've actually done it, their view is that when they do it next time, because they have all the costs of doing first of a kind and so on, they are confident the next time there will be able to do it at 30 per cent less than they have done it this time. So we have indicators that we will get that cost down quite significantly.

MS CONSTABLE: And of course the technologies are there and being – and already being implemented, so some companies around the world already have capture technologies that are now off the shelf and being used in projects. Boundary Dam is a good example of that where the capture technologies that they are using are technologies now that can be bought off the shelf and companies are not looking to put tests – untested technologies in to their commercial plants, as you would expect. So we will see some movement because we are still dealing with first of kind. So as we see more and more of these projects coming on line, the costs of course will come down. That statement of 30 per cent is really critical because we have seen the first brown coal power plant now. As that is rolled out and we see more and more, we will see the costs further reduced. Again, I just want to restate, we are talking about large capital investments, we are not talking about small capital investments here.

On the oxy-fuel, if I can just talk a little bit more about the oxy-fuel. That was an important project for Australia. The CS Energy and its consortium that involved some Japanese companies and there was a significant investment made by the Australian government, so 350 million dollar investment by Australia in the oxy-fuel capture process that now even though it has the whole demonstration has finished at the end of 2014, those learnings have been taken back in to Japan and the Japanese part of the consortium will consider next steps. So there are proponents now around the world that are looking very closely at oxy-fuel as a real option for carbon capture and storage. So we have finished the demonstration, we have done what we needed to do in Australia and now the next steps are being taken in terms of consideration of commercialisation.

MR JACOBI: Was that demonstration within the electricity sector, or is that demonstration at the chemical plant end?

MS CONSTABLE: No, it was at the electricity sector – at electricity sector, so at CS Energy, at the Callide Project in Queensland.

PROF COOK: They refurbished a (indistinct) that was already (indistinct) used for electricity production so it was – it is an example (indistinct)

MS CONSTABLE: We took it a step further because we took a small amount of the CO2, this is where we started to integrate what we were doing in Australia, even though it's very small and not joined up, it is still integrated to the point where we capture the CO2 and then stored about 100 tonnes of the CO2. It was taken by truck down to our Otway site and we injected that in to the (indistinct) so in that way carbon capture and storage is starting to become reality in making sure that we have got an integrated approach. So the oxy-fuel project from capture through to storage has helped demonstrate that in Australia.

MR JACOBI: Again, coming back to the summary for policy makers from 2005, it referred to the challenge of retrofitting existing plants with CO2 capture and the sorts of costs that are likely to be involved. I am just interested in your view about what you think the prospects are of retrofitting coal-fired power stations in Australia with carbon capture and storage?

MS CONSTABLE: So this comes down to the costs, and the costs - I was talking a little bit more about the study we're doing on levelised cost of electricity and we have in that considered the costs of a whole range of technologies, not just carbon capture and storage, but we go to the heart of renewables. We look at retrofitting in Australia and the costs around that. I'm not able to talk about what the final costs might be, because I don't want to give the Commission inappropriate information, particular because we're going through a stage of examining the preliminary data.

Of course it is possible to do that in Australia as it's occurring around the world already, but it does come down to cost and the best fit of a power station in Australia, and then where you might actually store that CO2. So that comes down to the transport and storage costs associated with the capture of the CO2. So the retrofitting is possible, but it becomes a matter of cost. We're likely to see that more so occurring internationally, with Australia being a fast follower down the track, and we're looking at what we might do from an Australian perspective out somewhere around that 2030 period as opposed to it being something that's considered right now.

There is no-one right at the moment that is considering retrofitting a power station at a commercial stage in 2015, and it's a cost - it's an economic situation. But this is a global effort and we're looking at the international effort and what we might do in Australia to help bring those costs down.

PROF COOK: I mean, it's worthwhile mentioning that CO2CRC has retro-fitted a small scale post combustion capture plant to the Hazelwood power station for example. So it's certainly possible and some of the earlier work by CO2CRC indicated conclusively that you could actually retrofit more cheaply than you could new build, which you'd think, "Well, that doesn't make sense."

But the reason for that is because an existing plant has all the approvals that it needs, you've got the land there and so on, you've got the exporting power systems all available there. So when you add all those up together, that actually amounts to more than the additional cost of the new build. Now, having said that, there's no way you're going to put a retrofit on a 50 year old plant. So it does depend on the age of the plant as well. But certainly retrofit is feasible, it depends on the circumstance, including as Tania says the distance to the storage site and so on.

MR JACOBI: Yes, can I just pick you up on two parts of the answer? I think first I want to deal with the experience that you had with respect to the Hazelwood plant, and I think we've got a slide that deals with (indistinct), and I think it might be the next slide.

MS CONSTABLE: Yes.

MR JACOBI: I'm just wondering if you can explain the nature of the retrofit that you considered there and the extent to which you might have had success or otherwise with respect to carbon capture with respect to that plant.

PROF COOK: Yes, it's building on a process called the Benfield Process which has been used for a long time, and there it uses potassium carbonate to strip out the carbon dioxide from the flu gasses, and it's a process that's been used for a long time. It's used in South Australia for instance in the Cooper

Basin, used by Santos there for pulling the CO2 out of gasses. But it has high costs associated with it.

So it's a good example actually of innovation, in that the question was that these - previously we've used liquid potassium carbonate (indistinct) solution. If we look at it as a slurry, can that decrease the costs, and it turns out that the costs can be decreased very significantly because you have much lower costs of stripping out your CO2 from the potassium carbonate. So that's what this is - you know, simplistically, it's all about dealing with potassium carbonate, a tried and true way of getting rid of CO2, but using it in a new sort of way as a slurry, and that's really what's happening here.

So it lowers the cost, it lowers the energy use. Potassium carbonate has low volatility, as it says there, which is different to many of the other solvents such as amines which are widely used. So it has a number of very positive features to it and the company which has really split off from CO2CRC, which is - I think it's called UNO Pty Ltd or something like that - is now pursuing this and talking to a number of potential partners and so on.

MS CONSTABLE: So it's pretty exciting because we developed a set of patents from this particular technology. It has been handed over to company and the inventors, some of whom sit in various universities, University of Melbourne, Monash University to name a couple of them. So seven inventors are sharing in this particular technology and are seeking now to commercialise it.

It didn't fit with where the CO2CRC was going in terms of our being a research provider, we're not there to commercialise these technologies. We're there to help get them off the ground and assist the industry to do that. But the UNO MK 3 certainly it does have potential in taking that next step as a very useful solvent technology for the purposes of capture.

MR JACOBI: Now, I noticed on the slide this reference to valuable by-products, and I'm just interested in understanding the extent to which the ability to use the CO2 in some way - I think we've had some evidence earlier in the week that the CO2 has been used in enhanced oil production, and that's underpinned some of the developments overseas. But the extent to which that there might be some economic outcome associated with carbon capture and storage might be necessary to drive its economics.

MS CONSTABLE: So that is happening more around the world. We have now an example in Australia where there's a value add, Air Liquide partnering with AGL in South Australia to utilise CO2, to use capture the AGL plant, capturing CO2 and using the by-product to produce carbonated water. So that's the first example in Australia where there is a by-product and a value add.

That's happening elsewhere in the world, and there are now quite a few projects, enhanced oil recovery being the most common in terms of the utilisation of the CO2, and Boundary Dam is another good example of that.

So that's the most common value add. Although it's a little bit more under wraps, a huge project in China, the GreenGen project, is also exploring the use of CO2 with a valuable by-product, again around carbonated water. There's a number of interested parties from around the world, governments; UK, United states; that are contributing to that in terms of making sure that there is a value add with the CO2, the extraction of the CO2, and putting a value on the carbon basically.

PROF COOK: The only thing I'd add to that is that the 2005 report estimated the total world use of CO2 was probably of the order of 200 million tonnes a year. So in other words, it's quite small compared to the total amount of CO2 that's emitted. That doesn't mean that's in no way to diminish it's relevance, because it is relevant and you do it where you can. It's not going to save the planet, but in certain circumstances it's a really good thing to do because you're making money out of it and you're decreasing the amount of CO2 going into the atmosphere.

MR JACOBI: I just want to pick up the other part of an answer you just gave earlier with respect to the distinction you drew between old coal fired power plants and newer ones, and I'm just wondering whether newer plants, and perhaps some of those that you referred to earlier when we started, are being designed in a way that more easily lends themselves to carbon capture and storage being fitted to them.

MS CONSTABLE: So I think this is an area that focussed people's attention at a multilateral level, and I can think of a couple of fora where this has received a lot of attention, the Carbon Sequestration Leadership Forum is one of those fora that has considered making sure that plants are capture ready around the world, and by capture ready that they're putting in technology that allows the retrofitting to occur when it becomes economical. So, you know, we're seeing different standards of technologies and governments ensuring that plants - that investors are putting into place new plants that are either capture ready or getting ready to be capture ready as part of their investments.

MR JACOBI: I was interested to understand what you think is going to be needed in terms of investment to get us to the point - again coming back to the 2014 summary for policymakers, it makes the observation that it hasn't yet been applied at scale to a large operational commercial fossil-fuel power plant, and I am just interested to understand what you think the steps are in terms of investment to get us to that particular point.

MS CONSTABLE: I don't think that's the case any more. I think that came into play before Boundary Dam got off the ground, and that occurred in October 2014. So that's no longer the case. It's not just a matter of being ready at the power plant capture stage. A lot of the work has to be done before that stage. You start with site characterisation. The work that we've done in Australia, you know, that's occurred over at least the last 11 years, so since CO2CRC has been in place and the research effort at, you know, those early 2000 years, enormous effort in making sure that site characterisation was the first stage, and that continues to be the case in Australia and around the world.

Unless you have got the right characterisation occurring in specific sites, because they are all going to be different around the world, you don't necessarily have exactly the right structures in the right places matched up with your sources of CO2 or whatever the industrial process might be, and the ability to store that CO2 close by. I do have a slide later on that talks about that.

So that's really the first stage that needs to be taken into account before you get anywhere near the capture. I really need to make sure that the Commission understand that and, of course, there's parallels that you could draw directly, Commissioner, with the nuclear power sector. Unless you have done all that work and you put your effort into, well, where would we be looking to store the leftover resources from nuclear energy, then you're not going to have the social licence to operate that particular plant or that particular sector.

So that's one of the stages that is critical, making sure that you've got all of the approvals in place, (1) it's legal, that you have got the right regulatory approaches in place, that you have looked at like any sort of investment in technologies that you have gone through. Now, if the financial processes - have you consulted well enough with the community, and that's going to be critical to any CCS and any technology being successful, and that at the end of the day all of those things need to come together as a suite of activities and actions to make the project successful and the sector successful.

Starting with carbon capture and storage, I think it's a technology we still haven't done enough work in making sure that the community understand. When you ask people what do they know about carbon capture and storage the answer is usually, "No, not very much," so we have to get better in communicating what we're all about and what carbon capture and storage can actually do in terms of mitigation of carbon dioxide.

PROF COOK: There's probably something else that - something I'd like to expand on and it's not - there's some additional things which are really important that are going to make CCS go ahead, and one is to have the right policy settings, of course, and Tania can certainly talk about that more than I can. That can include regulations to limit emissions and so on. At the moment the situation is why would anybody do it.

The power that you produce is cleaner and so on, but you don't get a cent more in terms of the electricity that you sell. So why would anybody do it at the present time, and the answer is, well, they don't, because they can't make money from it. There's nothing like the renewable energy targets or anything like that to say, you know, "Well, let's use CCS because that produces cleaner carbon." I don't know if you want to say anything about that, Tania.

MS CONSTABLE: I think policies are the domain of the Australian government and state governments around Australia. What I will say is that there are three types of regulatory approaches - or three types of approaches we see around the world. One is the regulatory approach, another is putting a price on carbon, and the third is a direct action approach. I think there's three examples around the world. So the US is largely looking at a regulatory approach and we have started to see projects coming, you know, on the ground because of that regulatory approach. I will say that the Gorgon project has become a reality because of that regulatory approach that we had in Australia in a requirement in Western Australia for the project to put carbon capture and storage into place before the approvals were given.

The EU, of course, has been going down the putting a price on carbon, but they have got a very low price on carbon, so there's not enough there at the moment for any fuel switching to occur and a reversal of the merit order of the projects. So until you see a price on carbon come up where that fuel switching starts to occur, it's a little bit harder but, of course, it is there and that's what a market mechanism does do.

Then, of course, there is the direct action approach that we have currently in Australia that you're seeing, you know, subsidies being given for various technologies and we are seeing small demonstration of projects, so pilot projects, demonstration of projects, and that's really very important for us to have in Australia because it's a complementary approach. We'll see what happens with Australia in terms of policy position that might be put forward by the new government in the future. So they're the three approaches that, you know, we see different reactions from investors around the world.

COMMISSIONER: Do you have a view about which is the most effective or is it too early to say?

MS CONSTABLE: Well, you know, I always think that a market-based approach is the best approach. If you put the right sort of frameworks in place and you have the right incentives there, so it could be a range of incentives, because there are market failures to many of these technologies, they have their limitations, so with a technology like carbon capture and storage, you need to have probably some additional incentives, as we've seen with renewables, to see these technologies rolled out.

I personally would like to see a market neutral approach on policy, and I think that the LRET, the renewable energy target approach, has been a good one in bringing forward the renewable energy technologies. I would like to see that rolled out to be more market neutral and allow all low emissions technologies to be considered as part of a portfolio approach for Australia. I think that that would make a difference to what we see in Australia, and I want to stress this is not a competition, this is about the market actually making a decision about what is the best technologies for the area that we have in Australia. But we're seeing that elsewhere in the world and I think that that's quite an effective approach.

So competitive neutrality around technologies, we see that put forward in the latest energy white paper, a neutral approach to all of the technologies, but there's been no specific policy change in allowing for other technologies within the equivalent of a renewable energy target. So I hedged a little bit, Commissioner. I know that.

COMMISSIONER: You hedged less than others.

PROF COOK: Is it worthwhile mentioning the - perhaps what they're doing in the UK with contract difference systems. What they're doing, they're investing 2 billion pounds into CCS projects. The problem that they could see is that there was no support (indistinct) management, and so they've implemented what we call contract difference system, which means - it's the difference between how much it costs you to produce the electricity, and how much people are prepared to pay. I mean, that's basically what it is.

That's really all you need in order to sell cleaner electricity into the system. The market is just not there at the moment if it's left to its own devices. The difficulty with putting the price on carbon is to put a price on carbon at the moment to get a CCS project going, and just relying on that, would cost, you know - it might even be $100 a tonne or something like that, which is just going to be so difficult to implement that it's just not going to happen. It would have a distorting impact right the way through the economy.

So that's why just a price on carbon alone is just not going to do it. So it will be interesting to see how the UK system works out. They're going through a tender process at the moment, and there's a couple of projects that are shortlist for that. So that will be an important learning experience.

MS CONSTABLE: So the two projects that have been shortlist in the UK is the Peterhead project and the White Rose project. Interestingly I've just actually come back from the UK, I was over there for a few days a couple of weeks ago. They made a very interesting statement at the conference that I was at. They have - they're in this tender process, and a decision will be made in March 2016. The statement was made it was, "Well, we'll either have two projects that will be successful, we'll have one project, or we'll have no projects."

I thought that was an interesting statement, because why would you say that unless it's not going to be zero, or it's not going to be two? It could be one, for instance, and in the last couple of days there's been a suggestion that some of the proponents within the White Rose project may not stay within that project. So it's an investment issue for the individual project, but it does indicate to me that there could be some - that, you know, it may end up being just one project out of the two that are in the competition.

But it's an interesting position that the UK do have, in that they've been very supportive of carbon capture and storage. That was very evident. It reminded me of where Australia was at around about 2007, 2008 stage in carbon capture and storage being very prominent in their thinking. So it was good to see.

COMMISSIONER: There's a number of things I want to pick up. The first is you made reference to the Gorgon development. I'm just interested to understand the nature of the regulations that were necessary to produce that outcome, and the nature of the technique that's been used there, and your view about its success or otherwise.

MS CONSTABLE: So this is again very exciting for Australia. The Gorgon project is due to come online in 2016, an LNG gas processing facility with carbon capture and storage attached to it, with the storage of the CO2 occurring very close to Barrow Island in the Dupuy Formation. This project is going to capture three to four million tonnes per annum of CO2, and store it in that structure. In order to put this into place a few things happened.

A signal by the Australian government that this project was supported in terms of the investment occurring in Australia, and it made a very small commitment financially, but a lot of effort was put into the support - vocal support from the government. I think the Western Australia government can be congratulated for its position also. So the Australian government gave the project $60 million. When you think back, it's not very much money given that it's a $60 billion project, and two billion of that is related to the storage of carbon dioxide.

So for that project to proceed through to being put into place next year is quite exciting, because it will be the largest CO2 carbon capture and storage project in the world coming online. So we have that in Australia, and again first of a kind, and very - that will, I think, send a signal to the world that Australia does have its first commercial sized plant injecting CO2 in Australia. So to actually achieve that, a couple of things occurred. The Western Australian government had to put into place the Barrow Island Act.

It sent a signal to say, "Yes, we'll approve your project, but you need to store the CO2." To facilitate that, the Barrow Island Act was put together, and it was specifically put together for that project. Now, there has been various views in Australia on what is appropriate. Should we have project-specific regulation? Should we have state regulation? Should we have a whole national approach? It's pretty hard to achieve on legislation in Australia.

But we've got a good approach offshore, just to just segue to something broader than that, where the Australian government has the Petroleum Greenhouse Gas Storage Act 2006 which was approved on 21 November 2008. That looks at all offshore areas. Now, that doesn't include the Gorgon Project, which sits in Western Australian waters. But the Gorgon Project is covered with other legislation that's required to report under the Environmental Protection and Biodiversity Conservation Act for environment issues. There are a few other Commonwealth pieces of legislation that are promised. But in terms of the storage, it's the Barrow Island Act that applies. It's very longwinded, I know.

COMMISSIONER: I'm just interested also to address you - you referred in an answer to the need to characterise areas for the purposes of storage, and I think we've got a slight - I'll pick it up. It's number 9. We dealt extensively earlier with the issue of capture, and I just wanted to pick up in terms of storage the sorts of analysis that you think need to be undertaken.

MS CONSTABLE: I'd like to highlight - so when work - a considerable amount of work was done on carbon capture and storage roadmap by industry, government, and researchers around Australia. In 2009, a part of that work involved the - a carbon taskforce being put together that looked at the transport and storage of sites around Australia. What we've just done very recently is do an update of that work. It will be ready at the end of October with the levelised costs for electricity works. So I have a portfolio of work that will be done within that. This particular slide refers to some of that work.

So the University of New South Wales, CO2CRC has been working with a range of proponents around Australia to bring this work up-to-date. What it shows is basically the blue bars that you have, that you see there, and there are two - the first half of the slide demonstrates Western Australia and the other - the right-hand side of the slide demonstrates the east coast of Australia. The blue bars indicate the source hubs, so where you would have various sources of

CO2 around Australia, and the size of those bars demonstrates the size of the emissions profile in each of those areas.

Then the red arrows show you where you would store that CO2, the different formations that have already been tested to various degrees. So some of it has been - the characterisation of the sites has been done very, very well, or some of it has been done in a preliminary sense. Then the lines that are matching that are the pipelines, the (indistinct) transport routes. So most of what we would need to do in Australia is going to involve pipelines, so that's an investment in itself. Pipelines to actually get it from the sources of CO2 to the sinks.

It doesn't necessarily match up that you have got the best sources - your sources of CO2 matched to your best sites. So you have got a variety of things that you need to consider, and there is another slide on the next page that shows you - this is just an example, but we do pick this up in a lot of detail in this particular study that looks at the various case studies. Short distances with high injectivity rates in terms of you can actually store large amounts of CO2, and that's where your costs are going to be lower, where you might have short distances and right out to poor injectivity, or you might have long distances where you're seeing that down the bottom, but you might have - long distances with high injectivity to long distances with low injectivity.

The costs of all of those are demonstrated in this particular graph. So this is work that was done in 2009 that we're updating right now in terms of what would that mean and how much per tonne of CO2 would it take, and then you, of course, then match that up with the whole picture in terms of carbon capture and storage as an economic possibility for Australia. So this work is essential to understand the big picture.

MR JACOBI: Am I right in thinking that there needs to be more characterisation done of other regions in order to reduce costs of installing infrastructure such as pipelines?

MS CONSTABLE: Yes. So what we have in Australia is we have already an infrastructure in place for power for electricity transmission and that's been in place, we have got a very mature grid compared to other parts of the world. If I think about China as an example, you know, they have a grid, a baby grid, but they have a grid Ours is quite mature, but what we don't have is the infrastructure, the pipeline infrastructure to support CCS as a reality in the future. So that's got to be given consideration. We know the routes that would need to be taken, but the infrastructure and the investment that is required. If you're thinking about the pathways forward and what it would take to actually get CCS off the ground and a reality in Australia, we need to think much more - you know, much differently than we have.

So this applies to any technology, not just CCS. We should be thinking about the system of energy in Australia as opposed to the private sector that just looks at it on a project by project basis. The governments of Australia industry should be looking at what does the system need to look like on energy in Australia, and one of those aspects is what would it take for these particular technologies to get off the ground and for CCS significant infrastructure around pipelines.

MR JACOBI: Just picking up that issue of systems, has there been an analysis done of the sorts of total system costs that would be associated with a world where fossil fuels were burned and carbon dioxide was emitted with CCS and the sort of system that one might have - we've heard from ClimateWorks where we might have a more decarbonised world using a wider range of renewable and other technologies.

MS CONSTABLE: So that word "decarbonise" is an interesting word because, you know, it's been captured by the renewable sector in some areas, but fossil fuels is decarbonising right now. I have just talked about Gorgon and the $2 billion investment that is being made in Australia. The coal industry is investing hundred and hundreds of billions of dollars around the decarbonisation of its industry, so all of the technologies that are in play are adding their bit to making sure that we get to a low emissions future. So the decarbonisation of our economy is essential, but all of the industry sectors are playing their part to make that happen.

MR JACOBI: I think we've got one last slide that shows a sedimentary basin, so I'm interested if you could explain the significance of that in terms of CCS.

MS CONSTABLE: Peter, I'll hand back to you on sediment.

PROF COOK: Maybe it's worthwhile just to set the scene going back to slide E which shows you the options for storage. In other words, there's not one geological model. There's a number of ways that you can store CO2 and that's shown here. The largest single opportunity is storing CO2 in deep saline acquifers which are sedimentary layers that can run or that can underlie thousands and thousands of square kilometres. So they're seen as having the largest volumetric opportunity.

Some of the easier opportunities are to put CO2 into depleted gas fields, not to get more oil out or anything like that but just because essentially you have created space. One of the important things to stress - and it's one of the misconceptions that lots of people have, not here I'm sure - is that you're putting CO2 into caves and voids and so on, you're not, of course, you're putting it into the pour space that's in the rocks that's presently occupied by saline water for the most part.

So what you're doing is you're looking for those opportunities and you're looking for it in sedimentary basins, and that brings us back to diagram 11 which is an assessment by CO2CRC about the potential opportunities that lie in some basins, and so you can see that some of these basins are highly suitable for storage and, for instance, the Cooper Basin in South Australia would be one of those basins which is seen as suitable. The Gippsland Basin down there in the south-east is another one, and that's the basin for the proposed CarbonNet Project which you might have seen some information on, and also the Otway Basin which is there on the South Australian and Victorian border which is also seen as a potentially good place for putting CO2 and that's where the Otway Project is and has been for a number of years.

Then you get to some basins which are more marginal and some that are perhaps unlikely. In some cases you're also balancing not only the rocks but also the potential opportunities for actually having a source seam match, because that's one of the important things, you know, it's all very well to have a source, but if you have got nowhere to put it into a sink then that's not going to work, if you have got a sink and there's no obvious source. I mean, for instance the Amadeus Basin there in the southern part of the Northern Territory or the Officer Basin in the northern part of South Australia have rocks that are suitable but, you know, there's no source, there's no significant source there. So you get to the stage where you're not going to run a pipeline 3000 kilometres, it's just not viable to do that.

So that's the basis of this diagram. It's a very coarse look at what the opportunities are, but it's a very good building block and, in fact, you know, there has been more detailed assessment of those various areas done by the storage task force three or four years ago. But CO2CRC started this about, I don't know, 12 years ago, something like that, maybe more than that, and that's been a building block that's been very useful in terms of assessing which areas might and might not be suitable.

MS CONSTABLE: The challenge for us is some of the industries and the areas that - so LNG gas, and it's fair to say that there are some fields that have high CO2 content particularly set up in the north-west of Australia. It's critical we find solutions to extracting that CO2, that high content CO2 out to ensure that (1), you know, they're economically viable but are able to reduce emissions, it's again those dual goals that we need to meet. So that's an area of focus for carbon capture and storage in Australia and the research organisations such as the CO2, CRC to be able to assist with that, the work we are doing at the Otway.

PROF COOK: Interestingly there, the area where you have got some of the highest CO_2 gas wells in Australia is actually in the Cooper Basin, in the northern part of South Australia, some of the south-east part of Queensland. There you have got up to 50 per cent CO_2 in the gas wells. Santos spent a lot of money separating out the CO_2 from that gas, probably about two million tonnes a year, one to two million tonnes a year but that is vented at the moment. They don't reinject that or anything else because that adds to the cost and so that is just vented to the atmosphere.

MR JACOBI: I think the last thing to pick up on is I understand you are having LCOE done and for your purposes, I think there are a number of slides that show LCOE as it relates to CCS. We had seen earlier ones and during the evidence of Mr Stock earlier in the week, I am just wondering whether you could take us through the implications of these?

MS CONSTABLE: So this is work that was done by the Global Carbon Capture and Storage Institute and so this is a global level but – so I have used this to give you an indication of what we will be doing at an Australian level. That work that we are doing in an Australian level will be ready at the end of October. So that will be a comparison of the technologies from 2015 looking at what could occur if a project proponent came forward now in the next couple of years and wanted to put a technology in to place, what would be the cost in today's dollars, 2015 through to 2030. We are not willing to look too far beyond that because the world might change again. So we are looking at 38 different technologies, but technologies that we know of, or just coming over the horizon such as energy storage is certainly in there. A whole range of technologies and we have got a stakeholder reference group that is made up of 41 organisations. We put out a press release, so this is a partnership made up of those 41 organisations. It is being driven by CO_2, CRC, CSIRO, ANLEC R&D Arena and it is being peer reviewed by a whole range of groups including the Resource Energy Economics Bureau within the Australian government.

Why I am mentioning this is because what we will have is a common set of data. The building blocks which you might make assessments across a whole range of technologies around Australia. I would caution that it can be used for inappropriate purposes in making a direct comparison straight away of the costs of technologies. You have got to take other things in to account in how would this be rolled out if it was put on to the national grid. What this study does is just form the building blocks, gives you a common set of data. So the Resource Energy Economics Bureau will pick this up in their Australian energy technology assessment and it will become the common set of data for Australia. So very appropriate to talk about in the context of what you might – you are doing with the nuclear Commission. The transport and storage will add to that. We are looking at what it might take at a regional level, so what does this mean in New South Wales, what does this mean in Queensland? What does it mean in Western Australia in terms of the technologies? And then specifically looking at technologies.

The other component of what we have in this package is CSIRO are drawing out their energy futures, so scenarios – what do the scenarios of these technologies – the projections of these technologies look like out to 2030. So it is not one organisation looking at this, it's a whole group of energy technology users, research providers, industry proponents, participating in this study. The base of which is being conducted by EPRI, out of the United States but on the ground in Australia. Or where there isn't examples of new projects, for example right at the moment carbon capture and storage, then international examples are used, Boundary Dam is a base case in terms of carbon capture and storage. So the work that you have here demonstrates - 5.2 demonstrates the levelised cost of electricity and the different costs of those technologies that you would see and down at one end of course, you have hydro power and at the other end solar thermal in terms of the costs overall. So what this demonstrates is the ranges of these technologies with the base cases being a conventional coal-fired plant and conventional natural gas-fired plant as those base cases.

I would say that this cannot be used in the Australian context because we are seeing some of the learnings change and from an Australian perspective, using real projects on the ground, some of the examples of what we are seeing here, perhaps will change. In the main, the ranges, the costs, the cost ranges are slightly different because we have got different exchange rates in Australia. We have got different productivity rates. Our private productivity is lower than the United States and that then varies across states. I will be getting the Productivity Commission to have a look at the work that we are doing to ensure that those productivity rates are examined very closely to determine whether the appropriateness of them. So the work in here is US based and based on what we are seeing on particular projects in the United States. The Gulf of Mexico is always used as the most efficient plants available and that tends to be a bit lower than you would want – than you would see in Australia. We are not the worst in terms of the costs and particularly productivity rates. I think Canada exceeds – well, is worse than us in terms of an assessment by others on productivity. But from an Australian point of view, that – our productivity levels are different and lower than what we would see in the US but that is – I don't think that will be a surprise to the Commission.

MR JACOBI: Perhaps if we can come just lastly to the chart that shows cost of abatement, which I think is chart 16. I am just interested to understand, with the work that is being done, is there going to be work done as a result of the analysis that you have just spoken about, in terms of cost of abatement of the technologies as well?

MS CONSTABLE: There is. We had a lot of discussion in the reference group about how we would look at the avoided cost of CO2 and the price on carbon and we have decided that we will include the price of carbon, even though there is not a price on carbon in Australia. The reason for that, so we will look at three scenarios. A low price on carbon, something down at below the $10 level, a mid-case, what would it take to change the merit order of what is already occurring in 2015, and then a high case that would allow for other technologies to come on and that would start to effect the conventional plants that we have in Australia. So those three cases are quite important in understanding what it would take to change the merit order. So that is the context of why we have included it and why it is included in this US study.

COMMISSIONER: I think that wraps it up. Thank you very much Professor Cook and Ms Constable for your evidence. We will adjourn until 7.00 tomorrow morning.

MATTER ADJOURNED AT 1.19 PM UNTIL FRIDAY, 2 OCTOBER 2015