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 cycle gas 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 CO_2 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 welds 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 Boeings. 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 agnostic 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]**