

Energy Technology Perspectives Scenarios & Strategies to 2050

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Good morning everyone and thank you for that kind introduction Andy. Dancing elephants are a hard act to follow but I'm going to try and again, it's a pleasure to be here. I first would like to say thanks to the Canadian Nuclear Association for the invitation and I'd be remiss if I didn't personally thank Murray and Claudia—where's Claudia—, Sanela, and all of you who helped bring me here today.

It's great to be back in Ottawa. I was born south of the border as you know. Don't hold that against me. I'm always pleased to be in Canada and it's a special time of year here. I actually went out on the canal last night and Andy, I recommend it. I hope you can get out there. It's great. I didn't realize it's the largest ice skating rink in the world. I'll add that to my resume. Next time you introduce me I'll have indeed skated on the largest ice rink in the world.

So again, happy to be here. A pleasure to be here. Honored and humbled to be here during a time of, I would describe it as a renaissance to the nuclear energy industry and I very much want to add to your tentative happiness this morning, I'm going to speak to you about an analysis, a piece of work that's been underway for actually seven years, at the International Energy Agency. It's *Energy Technology Perspectives—Scenarios and Strategies to 2050*. I'm going to stretch you here. I think most of our planning horizons may be a day at a time, a week at a time, a month at a time, in business, 10, 20 years, I'm going to ask you, for the next 30 minutes, to look ahead the next 50 years, five decades and we're going to talk about different energy technologies and how they might unfold, to help enhance our energy security, protect our environment and to continue to grow our economies.

I want to first remind you that we live in a world that's hungry for energy and our energy primarily comes from fossil energy. 2004 is the last year in which the IEA has officially approved statistics and by the way, all the data and numbers I'll be talking about this morning are number officially reported by your governments, Canada of course is a member of the IEA and by the way, it is the IEA, not the IAEA, those other folks live in Vienna, we live in Paris. But indeed, fossil energy is an important part of our energy portfolio and we're in a world where indeed energy security is on our mind. I was interested and a bit surprised, I understand energy security is a bit of an issue here in Ontario. I understand you've got some local gasoline distribution challenges. Good luck with that. I'm not going to talk about it this morning, but it just reminds us that energy security is something that we cope with day in and day out

and in our energy supply equation, again, fossil energy is important and nuclear energy, we think, as we look at our models, our analysis, is going to continue to be an important contributor today. It's about six percent of the portfolio.

I want to speak to the environment, just for a few minutes. I'm not going to spend a lot of time on the environment today, but environmental considerations help drive our models, if you will, and let me remind everyone that indeed, although it's cold outside today, global climate change is something that world leaders and citizens around the world, I think, are increasingly aware of, concerned about and although we are doing our best to reduce greenhouse gas emissions and comply with the various protocols, conventions and treaties and such, in fact the world's greenhouse gas emissions, no matter where you live, continue to grow and they grow rapidly, whether you're in the OECD, the wealthier countries of the world, the developing world or the transition world, greenhouse gas emissions continue to go up and I think something worth noting is that your neighbor to the south will be moving to the number two position very, very soon. China will overtake the United States, being the world's largest greenhouse gas producer in early 2009. So indeed the world's a changin' and the climate is changing, perhaps... that's what the IPCC tells us and we are concerned about greenhouse gas emissions.

The challenge that we face, at the International Energy Agency, and I think we all face it in energy community, is that there's lots of interesting technologies that are being developed that are on the shelf and we describe it as the technology challenge if you will, whether it's in the transport sector or the power supply sector, or managing energy in our homes or buildings. There's a broad portfolio of interesting technologies that are becoming more reliable, more efficient, their cost is coming down and indeed we're all confronted as consumers or as managers or as leaders of the private sector or in government, with what I described as the technology challenge. How can we take these technologies, use them to improve our energy security, to protect our environment, to grow our economies? And I'm going to speak to the technology challenge this morning because in fact we are interested at looking at the broad portfolio of technologies that we have around the world and looking at how they may play a role in improving our energy security and protecting our environment in the future.

Now I want to speak to your industry and I think this is the data that's very well known to you, but to remind you that indeed when we make our model runs, we look to the back, we look back, we call it back casting, to forecast in the future. And of course your industry grew a great deal during the 1970s, 1980s and it appears to be on the cusp of another period of good growth and I just remind you of this to kind of help set the stage for some of the model projections and the scenarios I'm going to describe to you in the next few minutes.

I also want to... again this is a graphic very familiar to you but I want to remind you that again, we take a look at a broad range of technologies when we model the future and we think 50 years ahead. Not only do we look at the technologies that are

currently in the research and development phase, but we also look at technologies which are just on the shelf or ready to be developed. And the nuclear industry of course multiple generations of new technologies coming down the pipeline are available today and when we make these model runs and scenarios I'm talking about in the next few minutes, we'll consider the broad portfolio of interesting technologies in the nuclear energy arena.

And finally, something that is on my mind at the IEA is that although we project what the opportunities might be to use technologies in the future, I'm very mindful that it takes a long time to build a power plant, to get the permits, to actually put together the finance, the construction teams and that's certainly true in your industry and you know it better than me. These are some numbers from the *World Energy Outlook*, published in 2006, the construction time of nuclear power plants and of course through an interesting story, one takes perhaps a decade or so to in fact site and license and construct and begin operating a nuclear plant, when you're looking ahead 50 years, all of a sudden 50 years doesn't look that far into the future.

Now, the driver for our work, this particular piece of work that I'm going to share with you today, is driven by the leaders of the Group of Eight. In 2005 they met in Gleneagles, in the United Kingdom, and they actually asked the IEA to take on 14 major tasks, including the analysis which I'm going to share with you this morning, and they specifically asked us, and I quote, "the IEA will advise on alternative energy scenarios and strategies, aimed at a clean, clever and competitive future." And indeed this is a pretty big job for us, although we have a lot of data, a lot of interesting models and a lot of very talented people at the IEA, to pull together an analysis, on a global scale, that deals with the different scales and the development of the technology, the finance and such—a pretty big job and as I mentioned at the outset, this actually represents seven years of work. We actually started the work well before we were asked the question by the Group of Eight leaders at Gleneagles, but a very big job, a job that... I want to describe it as a work in progress.

Now we reported our on the analysis at the St. Petersburg Summit of the Group of Eight, which was just about eight months ago and indeed we believe that this is an authoritative source of information looking at the competition between technologies and assess how they can make a difference in our lives, whether it's in energy security, protecting our environment or growing our economy. Now I understand that probably not everybody in the room is a modeler and I don't want to immerse you too deep in the modeling world but I think it's important to understand some of the assumptions that we made before I present the modeling results, so bear with me. There's probably one or two Markal modelers in the room, I see a couple of you out there but it's important that you know that in fact we look at business as usual, of course we're interested in what happens if we do nothing, if technology doesn't change, we don't change our habits and that's our baseline scenario. Then we look at a scenario where in fact we see greater investment in clean energy technologies and certainly Canada has been a leader in clean energy technologies, your

government, your private sector, has invested heavily in a wide variety of technologies, a portfolio of technologies, and I would describe that as the Accelerated Technology Scenario where the leading economies of the world continue to develop at a steady pace in technologies. And then finally the Technology Plus Scenario, that would be a scenario where in fact we dramatically change the way we do business and in fact governments, the private sector, we all redouble our efforts, if you will, and invest in clean energy technologies for the future.

Now as I mentioned for the multiple generations for nuclear energy technologies—we looked at the impact of research and development, demonstration and deployment measures. The model that I'm speaking to you today, we call it the ETP model—no surprise—does indeed consider technological changes, it's one of the few energy models in the world that does consider changing technology over time. We also drove this model and we could drive it with many different factors, but in the analysis I'm going to present today, we drove the model with changes in the way we evaluate carbon dioxide emissions. Now there are many ways to of course drive a model, but we chose a future where in fact carbon is valued at \$25 a ton and that could be valued through a tax, it could be valued that way, through a voluntary measure. There's lots of different ways to get the point where we, as a society—as a global society—value carbon at about \$25 a ton (carbon trades at about \$25 a ton, in the European trading system today, so indeed we think that's a very reasonable number).

And then finally we looked at different scenarios that they differ in terms of their assumptions, economic growth and different rates of technological development. In fact this graphic breaks down the different assumptions we made for different technologies. I'd like to underscore... let's go to the bottom line, the Tech Plus Scenario where in fact we looked at major breakthroughs in technologies, dramatic developments and deployment of the technologies. In the nuclear arena of course two big impediments, of course public acceptance, I work for the International Energy Agency and in fact we have some member countries of course who do not accept nuclear energy technology and do not operate plants, have no plans to operate plants; so we have to make at least one assumption that in fact that will stay the same. But we also assumed in the model runs that in fact the future is different though. With the emissions-free nuclear energy technology in fact, there would be a growing demand for it around the world in developed and developing countries. So these are the assumptions we made, with regard to the model runs and I'll be referring to them as I go through the presentation.

Now, the world's not the same and in fact this model, again, has a portfolio of about 1,500 competing technologies, lots of different assumptions. We also have different geographic regions around the world. Of course Canada is modeled as an economic unit, as well as your neighbor to the South, the United States, and you can read the maps. So this is how the model unfolds. It has a regional granularity—a question that I'm frequently asked, well when will you break it down on a country by country

level? That's the next book. So we're working on that right now. Okay, let's get to some data. This is global CO₂ emissions, from 2003 to 2050—again using the baseline, the ACT and the Tech Plus Scenarios—folks, if we don't do anything different, if the baseline stays the same, we're looking at a global growth of greenhouse gas emissions of about 137 per cent. We're pretty darn sure this is what the IPCC will report in a couple of months because indeed this graphic is in the Fourth Assessment Report. They adopted this model run and these conclusions. So in fact, a pretty gloomy picture with regard to business issues. Well, if we don't change the way we do business, greenhouse gas emissions are going to continue to grow. That said, it's not a horribly gloomy picture, if we continue to embrace clean energy technologies—carbon capture and storage, nuclear energy technologies, energy efficiency, renewables, all contribute to a cleaner energy future and, in the ACT and Map Scenarios again, where we're going to continue that steady, investment to the future, we see a point where by 2050, we could begin to stabilize greenhouse gas emissions—not bring them down but stabilize them, bring them back down to where we are today, if you will. It's only with the Technology Plus Scenario, that is if we have a redoubling of our efforts to improve and deploy clean energy technologies so greenhouse gas emissions actually begin to come down by 2050.

Now I realize that...I'm a... been involved in the client change negotiations for about 20 years, most of my career and in fact I understand that in the Kyoto Protocol and other negotiations, we're talking about a rapid decrease in greenhouse gas emissions. Our models don't show that. We don't think we can get there anytime soon. Only with the Technology Plus Scenario can we begin to actually reduce global greenhouse gas emissions by the middle of the century. Again, four or five decades from now. So, it's an interesting dichotomy between what's being negotiated in the climate negotiations and what we view as technologically feasible at the IEA.

A message that I think you've heard before but certainly these model runs reinforce it, is that improved energy efficiency is the most important contributor to greenhouse gas emissions and in fact, end use efficiency, no matter how you define it, in the transport sector, in homes, in your office place and such, lots of opportunities for improving greenhouse gas efficiency, excuse me, improving energy efficiency and reducing greenhouse gas emissions.

On the supply side of the equation of course, nuclear energy plays an important role and you'll see in a few minutes that we project nuclear energy to in fact continue to be deployed around the world and together with carbon capture and storage and other technologies, we believe the world's hunger for energy will be met by a broad portfolio of supply technologies. But if we want to get after greenhouse gas emissions today, of course energy efficiency is the easiest one to deploy, as we have the technology today and it's about 45 per cent, 44 per cent of the equation.

If you look at global electricity generation by fuel type and these were shares—I think it's important to point out to you that shares for coal, coal with carbon capture and storage, oil, gas, nuclear, hydro, biomass and a variety of other renewables. There's an important role for carbon, capture and storage. There's a reason I showed you the graphic at the very beginning and that is we live in a world awash in fossil energy and in fact coal production continues to grow, it grows at a very rapid pace. The world uses a lot of coal. The coal is collocated in some of the largest economies of the world, some of the most rapidly growing economies of the world and therefore we believe that carbon capture and storage will be used in conjunction with those great supplies of coal and the existing and new power plants being built each and every week, as a matter of fact, in China and other rapidly developing countries.

All that said, as we look into our crystal ball over the next 50 years, we see nuclear energy growing, at a healthy pace, across... again this is at a global scale, together with other sources of energy. We see renewables making a contribution. This is the most aggressive analysis that we've ever published at the IEA for the growth of nuclear energy. I'm quite proud of that. I think it's a very robust analysis and we'll see if our crystal ball is correct, but again, we see growth for nuclear energy in the future. I'll go into more detail in the next few slides.

This is a world energy, nuclear energy use for 2003 to 2050, again, same set of assumptions and baselines and scenarios and again we see nuclear energy growing rapidly, again with a redoubling of our efforts to develop and deploy and finance the technologies out to 2050. It can be a very important contributor to a world where we have a more secure supply of energy and a cleaner environment.

If you look at growth of electricity production, again my fuel and scenario type—this again 2003 to 2050, again, nuclear energy an important role together with other supply side technologies in producing electricity. We know that in fact electricity consumption continues to grow at a steady pace on a global scale. Certainly in the rapidly developing countries—China, India, Brazil, others—very rapid growth in electricity production. As Andy mentioned at the outset, Asia has been a leader on energy supply, power production and such. We think that will continue in the future and certainly there'll be a broad portfolio of technologies applied to meet this supply need, to help the consumers achieve the kind of quality of life that they aspire to. So... and nuclear energy certainly plays an important role in that equation.

Now, a story that, again, I think is well known to you but again I want to just share our analysis with you. It's one of the values of coming out to a group like this of course is when I get to the Q and A session, oh, hold on, you know, we don't agree with that number that you showed on slide number 32, this is one way of validating the numbers. But this is comparison of nuclear, coal and combined cycle gas generating costs under different coal and gas prices. This is again a modest discount rate. This is from the *World Energy Outlook* but of course the good news for your industry is that indeed the prices or the production prices are steady as we see

opportunities of... we think natural gas in the future will continue to increase in cost, coal will continue to go up and nuclear of course very steady in its cost—the generating cost in U.S. cents per kilowatt hour.

Another good story for Canada, identified uranium resources, again this is from the *World Energy Outlook* of 2006. Of course Canada, a major resource for uranium. We'll get to the supply of this in just a minute, but our analyses shows that indeed the world has abundant uranium supplies. I understand that... and we get a lot of questions at the IEA particularly from the press, are the supplies adequate to support the growth of nuclear energy in the future and of course our analysis, I think reinforces your analysis that indeed there's a good story, we do have the uranium resources in North America. They're roughly... they're distributed around the world and I think the geographic distribution is important, that they can be... the market forces can go to work, continue to work and in fact supply our uranium needs.

If you look at world uranium production, again, our latest statistics, of course Canada is at the top of that heap and I understand some of the producers are here in the room this morning, congratulations. Again, world uranium production in selected countries for 2004, again data from the *World Energy Outlook*, Canada, Australia, Kazakhstan, Russia down the list, major producers of uranium, so a good story for Canada there.

Then finally, world uranium production capability and reactor requirements, in the reference and alternative policy scenarios for again the *World Energy Outlook*, world uranium production, we see it going up in the future, supply, demand, forces at work here, but in fact we think it's a very positive story for the nuclear energy industry and again I think reinforcing what is well known to your industry.

Something that we get a lot of questions about, at the IEA, particularly from the press is what's the impact of increasing fuel prices as we live in a time of volatile fuel prices, this is an impact of a 50 per cent increase in fuel price on generating costs, again using a relatively low discount rate, from the *World Energy Outlook*, but of course a great story for the nuclear energy industry, with IGCC, coal, CCGT of course, very sensitive to impacts of changes in fuel price.

Now I'd like to wrap up my remarks by getting into a little bit more detail on the greenhouse gas emission story. Nuclear energy is, again, the low emissions alternative to power supply. Some pretty startling numbers here. These are CO₂ emissions and two of the scenarios that we looked at in this particular analysis for the OECD countries, i.e. the developed or the wealthy countries of the world and the developing countries and of course, for either group, the developed or the developing country, greenhouse gas emissions are going to continue to grow rapidly. It's about a 70 per cent increase for the OECD countries, a two and a half fold increase for the developing countries and not a very great story if we continue business as usual. Again with the applications of clean energy technologies, with

nuclear being part of that portfolio, we can drive down those emissions or in fact slow the growth of emissions in developing countries.

If we look at the CO₂ intensity of electricity production, again, the same set of scenarios, 2003 out to 2050, again looking at all the different alternative supply side opportunities with nuclear, renewables, carbon capture and storage, improved energy efficiency, again, we can improve the CO₂ intensity of electricity production. We know how to do it. The technologies are there. And, as a society, I think it's the political will that's needed to make the changes necessary to in fact reduce the CO₂ intensity of the emissions. If we look at CO₂ emission from electricity generation and source of reduction—a kind of a complicated slide but again the same story is in fact that clean energy technologies can make a very big difference in reducing our emissions—the very dramatic growth, 137 per cent growth in emissions. A wide variety, again a portfolio approach, is a message I'd like you to take away from my presentation today, with nuclear energy being a part of, a contributor to reducing greenhouse gas emissions, but energy efficiency, carbon capture and storage, renewable energy, nuclear, all making a contribution to a future where we reduce greenhouse gas emissions.

This is power sector CO₂ emissions per kilowatt hour and share of nuclear power and renewables—a lot of questions, we get a lot of questions about what's the future look like? We understand that in fact we're going to use our coal. We understand that carbon capture and storage can probably help us in those countries which have a lot of coal but what are the trade-offs between nuclear energy and renewable energy—whether it's wind or solar, biomass or hydro? This breaks it down on a country by country basis, starting with China, India, Australia, United States, down the list, and you can see that in fact there are different strategies, different scenarios, at a national level, the trade offs between the share of nuclear in the generation mix, versus renewables. We don't know if our crystal ball is right. Again, I hope you don't cling to any particular number. These are just scenarios of the future, but as we look at technological change, as we look at the acceptance of technologies and the finance of technologies and such, this is what our crystal ball shows for the major economies of the world.

And then finally, I'd look to drill down a little better on an important role here industry plays in reducing global greenhouse gas emissions. These are CO₂ emission reductions in two of the aggressive scenarios, due to nuclear power generation technologies. And keep in mind that as a global society, we emit about 7 gigatonnes of CO₂ per year—a big number, billions of tonnes and in fact when... as technologies come on line, whether it's a generation 2 or 3 or generation 4, your industry can play a very, very big role in reducing global greenhouse gas emissions. Again, a 1.8, 1.9, gigatonnes a year out of a 6 to 7 gigatonnes a year of global emissions. So you can play a very big part of the equation. You play a big part in reducing emissions today but as the industry grows, as your technologies are deployed, as they're accepted, they become more and more important as we begin to grapple with reducing greenhouse gas emissions.

I'm often asked, what are the pathways, you know, how do we get there? We're here in 2006, 2007 and what's the pathway, how do we get to 2050, towards cost competitiveness for the technologies and as we look into our model—and again this is a model that considers technological change, changes in the economy and such over the next few decades—in fact, we see an important role for the R&D stage today. We think, keep up the investments, they're needed to perfect the technologies, to drive the prices down, to deal with waste issues and such. But we see R&D ramping down because in fact we foresee that many of these technologies will continue to be improved, they'll be more widely accepted and they'll be more and more deployment over the next few decades. And this is just again, one picture of how we see it unfolding. It's a scenario. Again, a great opportunity for your industry to help us reduce our greenhouse gas emissions on a global scale.

So to kind of wrap this up this morning and I'll be happy to take some questions. I know I went through a lot of data this morning and I'm happy to address questions. But as we look into our crystal ball in these scenarios, by 2050, again, most of our energy continues to come from fossil energy. That said, we understand that in fact your nuclear energy and renewable energy will be important, but in fact, in most of the major economies of the world, they have long term large supplies of fossil energy whether it's coal, gas, petroleum, and we see, as we look to the future, this is going to continue to be important for the next several decades.

CO₂ emissions. It can be returned towards today's level by 2050. That's not the dramatic decrease in global greenhouse gas emissions that of course is being negotiated in the framework I mentioned on climate change, but this is the story as we see it using our best models and we think those will be reported out by the IPCC in the next few months. Our growth in electricity demand can be cut in half and that can be achieved through again, energy efficiency and at the end use sectors as well as on the supply side. We also see opportunities again for new generation sources, nuclear energy, renewable energy, and we're very concerned that in fact if we don't work more on the demand side of the equation, that in fact the demand for power production in the rapidly developing countries will continue to exacerbate their very severe local environmental issues as well as the global issues. I'm reminded that one out of every three citizens in China dies of heart and lung disease related to local air pollution and that's a big public health issue for them. Power generation can be largely decarbonized by 2050—decarbonized. That means that your industry is going to step up and make a very big contribution in the future. That's what our crystal ball says. Carbon capture and storage, nuclear energy, renewable energy, all helping to largely decarbonize the power sector by 2050.

That's a big message folks because in fact the other part of the equation, the transport sector, will not do as well in the next few decades. We don't see big changes in the transport sector. In fact decarbonizing the transport sector will take well beyond 2050—it could be achieved in the second half of the current century. But we believe that the power sector will lead the way and hats off to your industry

and other leaders in this technology. We're very pleased that in fact the power sector can take this leadership role because it's a big part of the greenhouse gas emission reduction equation. We have a lot more work to do on the transport sector. We have to figure out a way to in fact get to the hydrogen economy or other means because in fact rapidly growing emissions from the transport sector may continue growth in emissions.

So with that, I'll be glad to try to respond to your questions. I want to thank GE Canada for hosting the breakfast this morning and thank you for your kind attention. And I'm most grateful for the warm and kind hospitality of the Canadian Nuclear Association and the folks in Ottawa. I've enjoyed my visit here. Thank you Murray very much.