Webinar transcript

Integration of intermittent renewables and nuclear for a low carbon society: MIT-Japan Joint Study

The NICE Future initiative offered this webinar on 1 November 2018. It can be viewed at youtube.com/watch?v=-a-axHsnGUA. For more information, see nice-future.org/webinars.

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About the transcript

Because this transcript was created using transcription software, its content might not precisely represent the webinar.

Jordan

[Today’s webinar] will be focused on the Integration of Intermittent Renewables and Nuclear for Low Carbon Society, a joint study by MIT and Japan. Before we begin, I’ll quickly go over some of the webinar features. For audio you have two options. You may either listen through your computer or over-your-telephone. If you chose to listen through your computer, please select the “mic and speakers” option in the audio pane. If you choose to dial in by phone, please select the telephone option and a box on the right side will display the telephone number and audio pin you should use to dial in. If anyone is having technical difficulties with the webinar you may contact the GoToWebinar’s Help Desk at (888) 259-3826 for assistance with a US country code. For some housekeeping items, if you would like to ask questions, we ask that you use the "Questions" pane where you may type in your question. Also, the recording of today’s webinar of today’s presentation will be added to YouTube as a link provided on the slide and you’re welcome to watch it at any time after it’s posted after the presentation.

Today’s webinar agenda is centered around a presentation and panel discussion from our expert panelists on their recently-released joint study on the challenges and opportunities facing nuclear. Before we launch in to the presentation I will provide a quite introduction of today’s panelists. Then we will have a quick introduction from Japan, some people at the Ministry of Economy, METI, Ministry of Economy, Trade and Industry. Following the presentation, we will have a moderated discussion and we will have a question-and-answer session with the panelists. We’ll address the questions submitted by the audience.
Today we have two outstanding panelists to discuss our topic. Akira Omoto who is the Project Professor for the Department of Nuclear Engineering and Management at the University of Tokyo and Charles Forsberg, who is Director and principal investor for the MIT Salt-Cooled High Temperature Reactor Project and the Idaho National Laboratory University Led for Hybrid Energy Systems and with those introductions I would like to welcome our representative from Japan’s Ministry of Economy, Trade and Industry to start the webinar.

**Takehiro**

Thank you, Clarice. Hi, everyone. This is Takehiro from Japan, one of the Japanese colleagues of ______ Initiative and thank you for your participation today. I’m very happy about that and I’d like to, very shortly, introduce the concept of this initiative and this webinar. ______ Initiative is found under Free Energy Ministry this year and the concept is a good harmonization in my understanding of nuclear energy and renewable energy and there is some very ... a lot of challenges between the two energies of the harmonization and today we have a very interesting joint study from Japan and the United States addressing these issues and challenges so please find some new understanding from this webinar. Thank you.

**Jordan**

And now we’re ready to just go to the panelist presentations. I believe Dr. Omoto will be speaking first and so, Dr. Omoto, the floor is yours.

**Akira**

Thank you. Could you go to the first slide, Slide 0? Yes, thank you, thank you for your kind introduction and thank you for this opportunity. A little bit of a correction. I used to be working for the University of Tokyo but currently working for Tokyo Institute of Technology.

I am now speaking from Tokyo where it is very sunny. I cannot see any cloud in the sky with a temperature hovering around 15-20°C or around 50°F. On a sunny day like this in spring or autumn, solar accounts for more than 70 per cent of ______ supply in Kyushu Island with more than 10 ______ degree this island is one of the 4 major islands in Japan and this happens during the daytime or weekends. There as the left-side photo shows abundant growth courses are converted to solar-panel stations. Like that we see a significant increase of solar or winter color, which often causes an excess in the price of crops and even negative price in some part of the world. Often nuclear energy and the renewables are considered as in conflict with each other; however, both are important for supply of low-carbon energy. So how can we use nuclear and non-dispatchable solar and wind power in a complimentary manner in order to achieve decarbonization at the minimum cost burden to the society?

This is a focal point of this, our discussion, today. Next slide, please? This is the outline of our discussion today and this is primarily based on the joint study by MIT and Japan. After a brief introduction we will discuss what is required in the grid when intermittently renewables penetrate deeply and what is possible for integration of nuclear and intermittent renewable in low-carbon society. Next slide, please. First of all, let me discuss the economics of solar and wind.

According to OECD IEA, solar becomes the cheapest source of electricity generation in many places in the world, including China and India. Comparison of unsubsidized levelized cost of electricity by level is shown on this slide illustrates photovoltaic and wind are cheaper than nuclear or new build, however the cost does not include the social or environmental externalities nor intermittency-related cost such as battery, lock-up power or degree of stabilization. Next slide, please. This figure is hypothetical load o carb in Germany in 2030. It depicts that in marginal cost based kWh market intermittent renewables penetrate deep and threaten this load power-generating source such as coal or nuclear. Although this figure does
not reflect reality, it is still varied in a generic sense and visualizes the economic difficulty faced by nuclear power plants due to reduced amount of kW they produce.

Electricity price collapses with the share of non-dispatchable power generation sources is high. Prices often go negative in US due to production tax credit given to intermittent renewables. Now I'd like to hand over to Charles.

Charles

Could I have the next slide? I’m in Boston of course, which is at night and we’ll need to click the slide one more time to show the picture. The central problem or central challenge I should say with the renewables, non-dispatchable renewables, is price collapse. This figure shows as the wholesale price of electricity on the vertical axis and the time and hour per an 8th or time over 24 hours of one day in California. The red line shows what the wholesale price was in 2012.

The blue line shows what the price was in 2017. What happened in these 5 years was the installation of very large quantities of photovoltaic, which on weekends and other times of high solar input collapsed the price of electricity until it was negative in the middle of the day. At the same time the price of electricity increased slightly before sunrise and after sunset. Now obviously this type of price structure is very disadvantageous for wind, nuclear and solar. Nobody can pay for an electricity system with negative revenue and so what it requires is large subsidies for wind and solar to address the price collapse. At the same time, you have these peaks after—before—and-after—sunset when other power stations have to come on very quickly and produce power when the sun goes down. In short there’s a challenge that must be addressed because of the non-dispatchability of wind and solar. Could I have the next slide? Solar revenue collapses as we accelerate solar output. This is some figures from the MIT Future of Solar Energy Study and the red line shows average-price market prices as you add solar and the blue line shows the price revenue, price for revenue for PV as you add more solar and the solar penetration increases from about 6 per cent to 36 per cent and, of course, what is happening in the middle of the day when you have excess electricity, the price goes down and the revenue collapses at the same time. I’m gonna have the next slide you can see the consequences of this on a system-wide scale.

Now this shows the percentage of electricity from PV in many different countries as a function of time: Italy, Greece, Germany, Japan and Spain and what we see in each of these countries is that initially, as solar is installed it contributes widely to the grid’s power production and the percentage of electricity from solar goes up very rapidly but it levels off and it levels typically around eight per cent in Europe because if you have a lot of solar in the middle of the day adding additional solar in the middle of the day does not contribute additional electricity of the grid. You just have to shut down parts of your power-production system and so the question we will be addressing today is how to reduce that kind of challenge for wind and nuclear and solar. Could I have the next slide? Now MIT did an analysis of different power systems to determine what the effect was of different systems. One system, which is shown in the top figure, is we had had all energy sources (nuclear, wind, solar, coal, coal with sequestration) and we asked what would be the cost of electricity if you had a totally optimized system.

Optimized in this case is minimizing the average cost of electricity to the customer. So, the top slide is all sources of electricity. The bottom figure is all sources of electricity without carbon dioxide, without nuclear and, as you see, if you take out nuclear, the price of electricity goes up. Now what we’ve done is analysis for six different parts of the world, from left-to-right: Texas, New England, Beijing, another area of China, the United Kingdom and France. So we have six different electricity grids for with all energy sources and without nuclear and, as we can see, in each of the cases, as go to less and less CO2 emissions, in other words from left-to-right, from the blue, orange, grey, yellow, dark-blue lines, less-and-less CO2, prices go up but if you don’t have nuclear the prices go up more. And the problem of course is the non-dispatchability of renewables. The challenge of providing electricity when you do not have wind and when you do not have solar and that’s the challenge of nuclear, that’s a challenge for
renewables and the question is how do you integrate the two systems together to minimize the total cost to society? And I’ll pass this back to Professor Omoto.

**Akira**

Thank you. Now let us look at the data as we go, could you go to the next slide? The mere increase of the share of solar or wind power does not necessarily lead to greenhouse gas emission reduction or affordable price. This table shows both gCO2/kWh and cent/kWh are high in countries trying hard to increase the share of wind whereas countries like France or Sweden with high share of dispatchable green electricity, namely nuclear and hydro shows better performance in this context. I think generally speaking the difference arise from coal power generation portfolio and methods such as backup power to deal with renewables intermittency.

For your information, the target of UK Climate Change Committee is 50 cCO2/kWh and MIT’s recently both published in September says around 10 to 25 gCO2/kWh is required for 2° scenario. Globally the current average is around 500 gCO2/kWh, Japan is 540. The pie chart here shows that US, nuclear accounts for 60 per cent of green electricity followed by renewables. Globally nuclear power accounts for one-third of green, carbon-free electricity. Next slide please? Against this background, researchers at MIT and Japan (Tokyo Institute of Technology, University of Tokyo and so on) started working in 2015 on these four topics.

As they’re shown here, they range from cost of decarbonization, how nuclear can contribute to tackle the issue created by intermittency as well technological and institutional innovations. Can I move to the next slide? Next slide please? As the share of intermittent renewables increases the power system requires flexibility by three methods. One is the flexible generation, including load-following operation or baseload power, curtailment of excess power from renewable ... I mean the curtailment cut off the connection to the grid. Second is storage or hybrid production to trim this much in demand and the supply.

Third is smart grid management such as virtual power plant or peer-to-peer transaction among prosumers. And of course, supporting policy tools help their implementation. Going to the next slide, very often nuclear energy and renewables are considered as conflicting with each other. Nuclear side may say creating tariff or production tax credit for solar and wind are distorting market. The renewable side may nuclear destroys environment, however both nuclear and intermittent renewables do not emit greenhouse in the process power generation, both increase domestic energy supply, and both are capital-intensive, meaning a capacity factor is required for economics. Nuclear and intermittent renewables can complement each other rather than fighting each other. I think the role of nuclear energy for the carbonization, first of all supply of affordable, clean energy, not only to power _____ but also to transportation and industry sector. Second: Helping intermittent renewables to address adequacy issues in terms of kW and ΔkW. I’ll be talking about this a little bit later. Thirdly, power supply to negative emission technologies and so forth. To elaborate a little bit more on adequacy issue, adequacy of power system to ensure reliable supply can be measure kW value, kW over value and adjustment capability to changing to kW.

As it is shown on this table, intermittent renewables can compete in the market and merit order of marginal cost, however they have programs inadequacy of power system because their availability depends on whether conditions. There are clear differences between nuclear and intermittent renewable in adequacy measures of kW and ΔkW, as it is shown here, battery storage and complementary use with nuclear or some of France supposes intermittent renewables in ΔkW values. We’ll explain this in more detail in the next section. Go to the next slide. To enable complementary use of nuclear and intermittent renewables, we need innovation technology and the institutional tools. This section discusses such innovations. Next slide, please? Let us discuss three examples of complementary use. The first example shown here is thermal storage, which is possible for _____ by installing _____ generator and oversized turbine generator. Operational modalities that were enough electrify from solar or wind, right with the reactor may store a partial heat without changing some of the power in the core.
Then you store the heat for electricity generation when sun or wind is weak. In this way a nuclear power plant becomes not only an enabler of electricity production of intermittent renewables but also becomes more profitable since nuclear power plant decreases electricity production when it market price is low but produces when the price is high. I would like to hand over to Charles.

Charles

Okay thank you. May we have the next slide? The next couple of slides are going to go into the technology of why we want to couple heat storage with nuclear reactors to enable the integration of nuclear and renewables. As everybody knows you can store energy in the form of electricity, batteries, hydro and other technologies or you can store energy in the form of heat. Now the reason we are interested in heat storage is it’s cheaper than electricity storage. There have been many recent studies that have estimated electricity storage costs, that is using batteries, pumped hydro and other technologies of the terawatt scale and the typical costs come out around $340.00, $350.00/kWh. At those electricity storage costs, one is talking about doubling or tripling the costs of electricity. Now in the United States, the US Department of Energy has a goal for electricity battery storage of $150.00 a kWh. This is for the battery only. If you add the electronics, the costs are roughly double to the area in the neighborhood of about $300.00 per kW. DOE also has Heat Storage Goal. This is primarily associated with concentrated solar power systems and that goal is $15.00 a kWh, an order of magnitude less and that goal has been achieved at some solar power stations.

Because of the low cost of heat storage relative to electricity storage, we now have solar power plants, with heat storage whereas photo voltaic systems do not because the electricity storage technologies are more expensive. Could we turn to the next slide? The next slide shows the cost of different energy storage technologies, starting with sensible heat at the very top and going down through a wide variety of technologies with the cost on the horizontal access and what one finds out is that the sensible heat storage technologies as deployed are substantially cheaper than other technologies and that’s of course actually been demonstrated in the field as well as with mathematical calculations. Could we have the next slide? The next slide shows heat storage that enables a base-load reactor with variable electricity output. In the upper-left-hand corner we have the reactor. It operates at base load, a constant production of steam. All of the steam to the power cycle if there’s a high demand but if there’s a low demand the reactor sends some of its steam downward to the heat storage system so it’s a reactor, steady state, variable steam to the power cycle and to eat storage. When the demand for electricity is high, that is the price is high, the reactor sends all of its power, all of its steam to the power cycle and steam from each storage goes to the addition ... goes to the power cycle, as is shown by the arrow on the far right. So, what we have here is a reactor at steady state with variable electricity to the grid. There is however one other feature with heat storage. If there are times of very low electricity prices or negative prices we can take that electricity from the grid and use it to provide heat storage in our heat storage system and what this does is it provides a market that provides a minimum price for electricity and it eliminates negative price of electricity by dumping the excess electricity into heat storage.

So, what we have here is a system that provides electricity to the grid when the price is high, and the demand is high but can also absorb electricity from the grid and dump it into heat storage when the price is low. That characteristic of course greatly improves the economics of nuclear power, but it also improves the economics of wind and solar because there is a market of last resort, a market that will take very low-priced electricity and dump it into heat storage and thus raise the minimum price of electricity above zero. Could I have the next slide? And now there are many heat-storage technologies that couple—can couple—to light-water reactors and can produce peak power. Two of these technologies—steam accumulators and sensible heat—are commercially deployed on large, concentrated solar-power systems.
Four other technologies are in various stages of development, research-and-development. This is not a comprehensive list. People have been working on many new concepts as the market has changed and there are probably six or seven other concepts that are not shown in this picture. I'm gonna describe one heat-storage technology and may I have the next slide? And that is steam accumulators. This is the oldest storage technology for heat for the production of electricity and, of course, again, the target is $15.00 a KWh. Now we show a picture here of a steam accumulator on the right and what the steam accumulator does is when the price of electricity is low steam from the reactor is used to heat the hot water to high pressure and high temperature and the heat-storage capability is typically 20~40kWh/m³. When the price of electricity is high, the pressure relief valve is opened, and hot steam goes to the turbine to produce electricity. Could I have the next slide? That describes the technology as steam accumulators.

The first steam accumulator that was put on the electric grid was the Charlottenberg Power Station in Berlin. It was installed in 1929. It was a power source. To charge it was coal to produce steam in the middle of the night and to produce peak electricity in the middle of the day, roughly at 50 MWe with a separate turbine. So that's the technology of 1929. On the right we show the technology of 2017. This happens to be the Khi Solar Power Plant in South Africa, which has steam accumulators. You see the solar—concentrated solar power plant—on the top and you see at the base of it the steam accumulators, which are large tanks, below pictures of large tanks so this is the oldest technology but it's only one of several technologies that are also applicable to light-water reactors. In general, the technology is used by concentrated solar systems and the technology is used by light-water reactors are similar and, in many cases, identical because they have an identical goal: The storage of heat at times of excess production to produce steam at other times. With that description of heat storage, I will pass the baton back to Professor Omoto.

Akira

Thank you. Another example of complementary use is nuclear hybrid production to produce process heat or energy carrier such as hydrogen or transportation. By using excess thermal power from nuclear reactor when the sun or wind is supplying enough electricity it can be converted to producer energy carrier, for example hydrogen. Nuclear power plant does not necessarily have to remit itself to the power generation, but it can produce supply heat to local industry and also produce energy carrier for such as hydrogen for transportation. For this high-temperature reactor is necessary. Light-water reactor is not supplying high enough temperature. Switching products between electricity and other products can be done while reactor thermal power is kept constant. Japan Atomic Energy Authority, JAEA, has 30 MWe thermal or gas-cooled reactor. This is an experimental reactor, but it was 950°C. Separately JAEA has demonstrated hydrogen production by splitting water using thermochemical reaction on Level 3 scale. In the future I expect tests done for automatic response using control and ______ in order to switch products between electricity and hydrogen, following great demand change.

The picture here is not that of HTTL but it depicts a model gas-turbine high-temperature reactor for coal generation of electricity and hydrogen. Next slide, please? I think hydrogen is a leading candidate for hybrid energy systems. To give us sufficient impact, some prerequisites exist. First of all, most of the demand such as for cars, secondly, electricity must be by a large fraction of total production costs so as to afford to operate for hybrid production at part load. Thirdly, product must be storable, like natural gas. At this stage it is not clear whether there is any other coproduct at this scale to make a real difference. One other part of the renewables, power to gas project exists to produce hydrogen from surface electricity from wind by splitting water. Next slide please? Hybrid production includes supply of high-temperature steam as it processes heat to industry. This figure shows candidates that you will see the industry requires heat higher than 300°C as a whole. Existing light-water reactor cannot supply such high temperature. I think this pro-sectorial integration by complimentary use is important contemporary driver to advance reactor technologies to high temperature. Such reactors are high-temperature gas-cooled reactor, sodium-cooled fast reactor and molten salt reactor. So, Professor Forsberg, please?
Charles

Yes, could we have the next slide? I’d like to stand back a little further and take a look at the broader perspective in the integration of nuclear and intermittent renewable systems. What we’re talking about is flexible production of electricity, industrial heat, desalination of water and other products and the goal, of course, is the same goal in all cases. We want to be able to fully utilize all of the energy produced by nuclear, wind and solar. These are high-capital cost, low-operating cost technologies. If you operate them at half capacity you double the cost of energy and, for that reason, we need to operate all of these technologies at full load, maximum capacity and, of course, what that means is we have to design a system that can take the variable output of this and produce electricity, as needed, for the electricity grid but also find ways and methods to use excess energy when it’s available. Either dump it into storage or send it to industry or some combination so we have to think about the whole system, recognizing that, in addition to storage, we have the option of dumping thermal energy and electricity into the industrial sector in the form of heat with heat storage and we have the option of a variety of electricity-storage technologies, including electric thermal-storage technologies. So, it’s important to think about the system, as a whole, recognizing we could also dump excess energy into the industrial sector when we have excess production from these sources. Of course, we do need to think about collocation and the management of the entire system by a single entity so there’s a coordination activity that is required to make efficient use of these expensive generating technologies in the sense that they’re capital-intensive and low-cost production of energy only happens if we fully utilize them. Could I have the next slide?

Now there a couple of institutional issues that need to be addressed. First, we need to reduce price collapse by avoiding mechanisms such as production tax credit that subsidized excess electricity production when it’s not needed. Negative price of electricity is not a good idea. It’s not good wind. It’s not good for solar. It’s not good for society so we need to have our incentives for efficient use of all electricity and not do some crazy things to the market. The second, we need greenhouse emission reduction policies by changing the policy tools to support all low-carbon energy sources equally (nuclear, wind and solar) and to work out what quantities of nuclear, wind and solar will change, depending upon of course location and local-resource availability of the renewables. Third, we need to enable high-capacity factors for capital-intensive generating facilities. This includes, of course grid upgrades to reduce curtailments of renewable energy sources and incentives for all types of storage, including heat storage. Last, we need to enable flexibility in resource management (smart grids, demand-side management and a variety of other technologies that can efficiently use the energy when it is available).

Could I have the last slide? Could I have the next slide? Okay there it is. Takeaway message: Shared goal by nuclear and intermittent renewables, achieving a level of decarbonization at minimum cost to society. We emphasize the cost factor because the problem is that if energy doubles or becomes much more expensive it becomes a very large social burden to society because energy is 6–8 per cent of the Gross National Product. The methods are we can sue complementary use of nuclear and renewable systems for flexibility. This includes flexible generation, storage or hybrid systems and smart grid management. Now what is noteworthy about these different technologies is there was no incentive to deploy these when you have fossil fuels. When you have a fossil-fuel system, the answer is if you need less electricity, don’t burn as much of the coal, oil or natural gas. So it’s an efficient way of operating but that is not true with nuclear and renewables so we need a new set of technologies that appropriate integrate these technologies together to minimize cost and that brings us to our third conclusion: The need for technology and institutional innovations and a joint roadmap for nuclear and intermittent renewables in option space that would provide real help on the path going forward. With that I think we can open up the discussion to the viewers and see if they have any questions and I’ll turn this over to the moderator who will select which questions should be answered and which people are called up on first.
Jordan

Thank you so much Dr. Omoto and Dr. Forsberg. We really appreciate that. That was an excellent overview and we are loving it. We wanna remind everyone to go ahead and submit your questions. We have a few audience questions, but we'll probably have time for a few more so feel free to keep submitting questions and we'll get to them as best we can. If we do not have time to get to all of the questions, then we will also follow up with the presenters and hopefully if they have time, we'll answer them and get them back to people who ask them. So, with our questions, we had a couple of different categories of questions and so I'm gonna try to group them together and do my best on that. The first one was actually interesting about for people who have—from someone who seems to have—read the study about a carbon price. How does things like a carbon price factor into your analysis? What is the lowest price option for decarbonization? In the United States I don't think we have a carbon price. Japan, Dr. Omoto, I guess we'll ask you first. Is there a carbon price in Japan?

Akira

Well, in fact, there is no direct carbon tax, however the indirectly there is the carbon tax through the transportation system, for an example.

Jordan

Thank you and to either of you, Dr. Forsberg or Dr. Omoto, how does the carbon tax affect some of your calculations or does it factor into your analysis in the report?

Charles

Let me answer this. The—we have a—challenge here. We're changing the system, an energy system based on fossil fuels to a low-carbon society. Neither you nor I nor anybody else has a good feel of what the right selection of technologies will be to minimize cost. The thing about a carbon tax is it's a way to force people off of carbon to allow the market to figure out the lowest-cost solution and we support a carbon tax because of our concern about the cost structure of getting off of carbon. If it's too expensive, the penalties to society will be too large and, in effect, we will not get off carbon so it's important find the most efficient pathway to get off of carbon, recognizing our ignorance and the strategy to do that, which most economists support is a carbon tax and let the market figure out what technologies, what combination of technologies work the best.

Jordan

Thank you so much and, in a similar question to that, some people were discussing or asking about carbon capture. We didn't see a lot of carbon capture in your presentations. Does carbon capture have a role to play in any of this and, if so, what prices where does it possibly get modeled at and it becomes cost effective to implement?

Charles

This is Charles but I'll let Professor Omoto answer that first.

Akira

Okay I think in order to achieve the target of restricting warming to within 2°C to a pre-industrial level they require energy saving and increase of the free energy, however such majors may fail, for an example, the saving. In such cases not only major sanction but removal of generated CO2s by such means forestation, direct-air capture and carbon storage by the use of based biomass with carbon capture and storage may need to be implemented. As I had explained in my presentation the nuclear would be able to assist by supplying power to negative-emission technologies. For an example forestation
requires watering, reverse osmosis to produce potable water and its transportation by pump and that air capture, the energy cost of direct air capture would be in the range of 1500 or 2300, which is $420.00 or $630.00 per ton CO2 or grid, according to some information available on web. So, the supplying cheap electricity from nuclear to assist negative-emission technologies will be maybe a part of the duty of the nuclear energy in the future. Charles?

**Charles**

I don't think I have anything to add to that.

**Jordan**

Thank you very much for that. We got some questions also about negative-emission technology. Did you wanna have anything else you wanted to say on what negative-emission technology is? You mentioned there but I don’t think it was explained in the presentation.

**Charles**

Professor Omoto, I’ll let you answer that.

**Akira**

Yes, the negative-emission technologies, basically to remove CO2 in the air but there is means as I mentioned before forestation for direct-air capture and the use of biomass with carbon capture and storage. These technologies are being development very rapidly and there is some experimental scale facilities, there, here and there.

**Jordan**

Awesome. Thank you so much so now, kinda switching gears a little bit, we had some questions about the design of these hybrid plants. Specifically, the first one that came up was about hydrogen so nuclear reactors are often very big. How flexible is something like a hydrogen-production process? How quickly could it ramp and how flexible is it to accommodating changes in grid electricity?

**Akira**

Well, in fact, there is no testing done yet by using a real high-temperature gas-cooled reactor but the researchers at JAEA, Japan Atomic Energy Authority, are working on this topic and, basically, the control is done by use of the control valve and bypass valves in a way to channel to turbine generator, channel heat to turbine generator or to hydrogen-production facilities. I hope that in the future by using HTGR the testing will be done to prove that such a control is possible. Unfortunately, in the aftermath of 3/11, I mean, 2011, the earthquake and tsunami, in 2011, the HTGR is currently idle and hopefully we will restart sometime in autumn next year so, at that time, hopefully such an automatic response using control and bypass valves would be done.

**Jordan**

Awesome. Thank you and actually there was kind of a follow-up question for that. In some of the designs in the report it looked like there was an intermediate heat storage that was used as a buffer. Is that always necessary, if you have a variable output, that quickly ramps on hydrogen production or can you do it without an intermediate heat storage?
Akira

Well to my knowledge, the automatic response using control valve and bypass valves in HTGR, high-temperature gas-cooled reactor, would not need some supplementary steam generator or some heat storage but this will be discussed further after the experimental testing using HTGR, I think.

Jordan

Awesome. Thank you and so we’re gonna switch gears again because we had a lot of questions come in about some of the cost of storage but just in case people weren’t quite aware please feel free to submit your questions at any time. We are still taking them, and we will of course always try to follow up, if possible, with our presenters. So, changing kind of directions a little bit and in that subject of storage, one of the things that was noticed by presenters is there wasn’t a lot of talk of pumped hydrogen storage or pumped hydroelectric storage, things like pumped water storage. Do you have any research with that or what the costs are and how that plays into decarbonization?

Charles

This is Charles Forsberg. The central question here is the availability of appropriate sights, which depends very much on the country you’re in. If you’re in Norway, no problem, if you’re in the Central United States, no hills so the availability of that option is very, very sight-specific and that’s why it received less attention than other kinds of storage technologies, you know? It’s great if you happen to have the right amount of rainfall and the right mountains but, otherwise, it’s just not an option.

Akira

Um.

Jordan

Thank you very much. Oh, go ahead, Dr. Omoto. Did you have something you wanted to say?

Akira

Yes, let me supplement by saying that pump storage is very widely done in Japan. Actually, in most utility companies in Japan they have pump-storage capacity; however, the further expansion will not be easy because of the environmental concern. The—I have touched a little bit about the—possible curtailment of the excess electricity from solar or wind. Actually, in Japan, in Kyushu Island, as I have mentioned, at the early … in the beginning of my speech, the curtailment of the solar electricity is one of the biggest concerns that which is the reality and will be done every weekend during the springtime or the autumn but before curtailment there is a predicated. One is the thermal forestation with the minimum, the power generation by thermal power will be minimized and, second, predicated, thermal storage is implemented as much as possible and if these two does not satisfy, does not still satisfy the condition then curtailment of the electricity production, electricity connection to the grid from solar is implemented.

Jordan

Thank you very much for that, Dr. Omoto and so as kind of one more follow-up to this storage question, what were some of the costs that you projected batteries to go down to? I know you talked a little about projecting the price of batteries over time. What were some of the prices estimated by this study over time for battery storage?

Charles

We used ... what we did is we looked at what’s in the literature with people who’ve spent a great deal more time than we have in looking at battery storage and they’ve looked at a wide variety of systems
and they end up around $300.00, $350.00 a kWh. The reasons are actually quite important to understand. When you make anything the cost of that production depends on the cost of raw materials. One of the reasons solar photovoltaic has gone down is that the raw material is silicon, which makes up much of the earth’s crust. Batteries or at least the batteries that people are considering have expensive materials such as lithium and cobalt and if you start with an expensive material, you end up with an expensive product. This is why gold bracelets cost more than steel bracelets and the problem is not a technology problem, the problem is this cost of raw materials and batteries are intrinsically high-cost, have high-cost starting materials, whereas heat storage, intrinsically, has very low-cost storage, very low-cost raw materials so this all comes back to the cost of the raw materials that go into your storage technology and that is why each storage is so much cheaper than the electrical-storage technologies, you know? Even if you technological advances, the fundamental cost structure will be ultimately determined by what is the cost of raw materials and cheap raw materials as starting points, cheap product, expensive raw materials as a starting point, expensive products.

**Jordan**

Thank you very much. As a follow-up question to that, one participant asked, or one attendee asked how many times a year does thermal-energy storage have to cycle to make it cost-effective? I know you put in the presentation around $15.00 per kWh. Is that? What does that correlate to in terms of discharge cycle for the Americans?

**Charles**

Well the cost structure’s about a factor of 10 less so it depends on the market/markets you’re in but obviously you’d obviously you’d need far fewer cycles. You may need only a 4th or a 5th as many cycles as you will with electricity storage, and you know it all goes back to the cost of raw materials in the system. If you have very expensive materials, you would just have to have a lot of cycles-per-year and if you don’t have a lotta cycles-per-year it becomes prohibitively expensive.

**Jordan**

Thank you and in that subject, I guess I’m not sure if it’s classified as always storage or the different process, but one attendee wanted to know about other types of chemical processes that could be used for nuclear. They mentioned making synthetic gasoline, diesel or aviation fuel with heat from the reactor. Is this being looked at or not looked at and, if so, why?

**Charles**

There is a lot of work, looking at different hybrid systems, energy systems. Of course, the big markets, the really large markets in this are ones that produce transport fuels and the logical transport fuels that people are looking at are first, A, hydrogen and, second, biofuels. Now it turns out in the biofuels. Now it turns out in the biofuels production it would require a lot of heat so if you have nuclear heat available, you have a lower cost of the production of converting biomass into biofuels but the big markets, simply because of that’s where the energy is are the transport markets and, of course, there’s a competition here between people who are pushing the production of hydrogen as a transport fuel versus biofuels versus ammonia versus other technologies but clearly the place that nuclear energy will play in that world in terms of large-scale chemicals are the ones that are used in the transport sector.

**Jordan**

Thank you so much so we have kind of one more question in the technical realm, kind of cost realm and one participant was wondering what are some of the overnight costs you assumed in the United States and in Japan for nuclear reactors to produce these estimates?
Charles

Yeah in the MIT Future of Nuclear Power Study, it was $5500.00 per kW. I’m not sure what it was in the other countries. I don’t remember. I just remember the US number was $5500.00 per kW. Of course, what’s … when you do these optimization studies of what is the optimum system, you try different numbers and what you find out in all cases is the low-cost option is some combination of nuclear, wind and solar. What happens if you have the cost of nuclear goes down, there’s more nuclear if there’s cost less.

If the cost goes up, you have less nuclear, but the economic optimizations always shows a combination of those because a long-term as long-term energy storage is more expensive than having nuclear in-the-mix. So, you know the relative costs affect the ratio of what you sue it, it doesn’t affect the fact that you have all of the technologies in-the-mix. All of the technologies generally minimize the cost.

Akira

Okay I’ll try to in response supplement a little bit. In this overnight investment cost or nuclear build there is no exact date right now although Japan has three nuclear power plants under construction. That was these are the units, which suspended construction by 3/11 Disaster in 2011 so when Japan starts new construction sometime in the future the real data will come in but I think, like other countries, $5000.00 or $600.00 per-kW might be conceivable but in the case of Europe and the states they are constructing first-of-kind plant, like, 80000 or EPR. After the experience construction has been exhausted 20 or 30 years ago so the coupling by … coupled by these 2 effects, the cost of the new investment will be—has been—increased significantly and however this situation will be a little bit different if the country continues construction of the plants continuously like the case of the Korea. So, I cannot generalize the overnight cost. It depends on countries’ specifics, especially if the country has a continued nuclear-energy economic program or not.

Jordan

Thank you very much. That was an excellent answer and so we are running out of time so I think we’ll ask one more question and then we’ll give our presenters time to have any wrap-up statements they might wanna add. So, our final question of the night is what do you think the NICE Future could or should do to advance these nuclear-renewable systems? This is after all a NICE Future initiative webinar and so what do you think the NICE Future could do for these types of systems to be advanced in both Japan and the United States and in other countries?

Akira

Well, I think …

Charles

I got it.

Akira

Yep, go ahead.

Charles

I’ll let Professor Omoto … Professor Omoto start on this, on the discussion.
Akira

Okay, I think most important is to think about what the government can do to accelerate such things like complementary views as a part of the NICE Future initiative. In that context I think two things are conceivable. One is to create a joint roadmap by nuclear and intermittent renewable and provide funding for R&D. Since there are commonalities in either technology such as storage and hybrid production this already mentioned at the last part of Professor Forsberg’s presentation and, secondly, to give ______ to assure the capacity and the capability to adjust the demanded change in the market, in order to incentivize actions for storage and hybrid production so Charles?

Charles

I would concur with that with an emphasis on the observation that we’re getting off of carbon as a fuel that we can store easily and which we’ve used for roughly 300000 years as we’ve gone from the camping fire to the gas turbine. And so we’re heading to a future with a totally different set of energy options and what there is, is a need to explore that option space and lay out some roadmaps, recognizing that we have a lot of things we don’t know and it’s just gonna take time to sort out that option space but we don’t have a lot of time because of the greenhouse gas concern so it’s time really take a serious look at how you can put all the pieces together in a way that minimizes the total cost to society because if we do not keep those costs under control it will be very difficult to get off of carbon if it results in a significant decrease in the standard of living. So, in the end of the day, this is as much about economics as it is about technology because if we can’t get the economics right, we’re gonna keep on burning fossil fuels. That is the reality, you know. Countries don’t burn coal because they like coal, they burn coal because it’s cheap and they need it to maintain their stand of living so I think it’s important to get started and to push hard and figure out how all of these new pieces that previously weren’t working together should work together to minimize total cost.

Jordan

That was … seems like an excellent statement to end on. We are out of time so, first off, I wanna say thank you so much to everyone who presented. Our presenters were awesome. Thank you so much for all of our attendees as well. If there are any questions that we did not get to we will follow up and we’ll get those back to you and, for now, just thank you, everyone for attending and have a good evening or morning.