Paul Torcellini: Hello. This is Paul Torcellini. I'm an engineer at the National Renewable Energy Lab, and I'm excited to kick off our 2022 Better Buildings Summer webinars today. We're gonna be talking about large-scale heat pumps, and in particular, geothermal heat pumps. So, let's go to the next slide.

Go to the next slide.

And you continue on.

All right. So, just to kind of frame the discussion about heat pumps. Really, heat pumps are moving heat from a colder temperature location to a warmer temperature, and today, we're going to talk a lot about the heating side. And in order to make that heat move, we're gonna put energy in. That refrigerant absorbs the heat, evaporates, and that refrigerant gas is compressed.

Then, it releases it when it is condensed at that high temperature. It is a closed-loop system so that no refrigerant is added or lost from this system. Next slide.

So, when we talk about heating, we actually put the building – or a collection of buildings, as we'll see today – on the hot side. Often, we can take that low temperature – either from the outdoors or from the ground – and then, put some energy in – usually electricity – and, in fact, we're gonna focus on electrical solutions today to move that heat to that high temperature. Next slide.

And so, some of what helps with the efficiency of this is that the slower that temperature difference is from the low side to the high side, the easier it is to move that heat. So, if it's cold outside, heating is more work. But many heat pumps still work when that outside air temperature is very low. Today, we're gonna talk about some larger scale systems and, in particular, some ground source heat pump systems, and in that case, it's taking advantage that the ground is warmer than the air, and that can improve the efficiency of that system and so, it minimizes the effort to really pump that heat from that low temperature to the high temperature. Typically, it's two to five times more efficient to move the heat than it is to generate it, such as with electric resistance heaters. Next slide.

So, when we're pulling that heat from the ground, there's different ways of doing it. That ground tends to maintain a pretty constant temperature year-round, which allows that heat pump to work more efficiently. In the summer time, we reverse the process and take the heat that's in the building and extract it and push it back into the ground. Now, note that this concept of a ground-source heat pump is different than natural hot water that you might find deep in the ground, and you think of something like true geothermal resources like Old Faithful where there's naturally hot water and steam coming out of the ground. Today, we're gonna just focus on using the ground as kind of a large-scale storage mechanism, where that heat is pretty constant year-round or that temperature is constant year-round in the ground. Next slide.

So, a lot of times, these are going to be large systems, and we talk about district-scale geothermal heat pumps, and it's taking advantages of those temperatures that are a little bit deeper in the ground. Typical would be more than 30 feet and we've got a constant temperature between 50 and 59 degrees. And we're going to exchange that heat with the ground, and we could have many, many bore holes or wells that are connected together in order to meet whatever that load is. The larger the system, typically, we need more of these wells to meet those loads. We bring that energy to the surface, and we distribute it either with hot or cold water to buildings, and what we are seeing is that this is a technology we can use – and we'll see some examples later – to replace existing district systems.

Sometimes, we're using hybrid systems where we're still using a little bit of fossil fuel in the mix, but relying primarily on the ability to pump that heat from the ground. Buildings can be solely retrofitted and then added to the system as we go along, and we're gonna learn about what has to happen on the building side, as well as what's happening on the ground side today. Next slide.

We're seeing a rampant increase in the use of these technologies worldwide, and you can see some examples here of kind of the sheer magnitude of that information, and that if you do something like this – and I hope that our speakers really bring this to light today – that you're not necessarily first. This is a proven technology, and that there are many people using this. And we're seeing about a three percent annual growth rate in the United States with this. There are a large number of smaller systems that are residential, and we're seeing a growing number of commercial – and especially large-scale commercial. Next slide.

So, at DOE, we have different offices that focus on the technologies. There's one dedicated to thinking about geothermal technologies, and they're going to be putting out a funding opportunity announcement on community geothermal heating and cooling systems. And there's a little bit of discussion about – on the slide – about what this project is. It's really to encourage innovation approaches, to making some of these large-scale systems work and giving those examples. And so, there is some information available on the geothermal website, as well as being able to sign up for their newsletter if you want to stay current with the information that's coming out of DOE. Next slide.

I've also put on here a couple of other resources if you want more information just about heat pumps in general. There are some short videos that discuss how they work, and there's also, more broadly, an HVAC and water heating decarbonization guide that was put out by Better Buildings, and it's on the Better Building's Solution Center. And that covers not only the ground source, but also, air source heat pumps. So, basically, if you have an existing system today and it's using a fossil fuel, this kind of maps out what some opportunities are on the electric side. So, next slide.

Let's move to the next slide.

All right. So, today, we are going to be using Slido as our engagement platform and so, you can enter the code – go to Slido.com and enter the code "DOE". In this, you can ask your questions. Please, do not use the Zoom portion for your questions, but use Slido. And let's see.

I think I lost the slides here. There we go. And so, please, do join us at Slido.com and again, #DOE will get you in there. Next slide.

I want to start off today with some questions – give you a little practice with Slido, get you engaged with that, and so, I see results coming in now – so, answering the poll. We've got a lot of folks from local government, as well as contractors and consultants. Again, a lot of higher ed and some state governments so, definitely areas where we see opportunity for some of these large scale. So, we'll give this just another second or so to kind of finish out and scrolling up and down and seeing what some of our options are here. Great.

So, hopefully, we'll get some of your questions answered and show you some good examples of applications on the large-scale heat pump side. Let's move to the next question.

So, we'd like to know a little bit about your experience with heat pumps and if you've used them for HVAC systems. And it looks like we've got a big crew that have – over half have used them some of the time, especially if we add "most of the time". And, as we go along – and maybe during the question part – some of the concerns around the "Never" category and what some of your thoughts are – we can have that discussion later on in the webinar. Let's move to the next question.

And so, the next question is – what is your primary motivation for using heat pumps and HVAC systems? Definitely have a large majority that are thinking about it as a decarbonization strategy. So, I think our speakers will be able to address that pretty directly as we go on. Next slide.

And then, what are the barriers for using heat pumps for your HVAC systems? So, we had a lot of people who said "sometimes" and so, we'd like to find out what your sometimes – what would help you think about them more and what some of the challenges that you have are. Right around half want to discuss the upfront costs, and I think our speakers will be able to talk about some of the hows and whys their organizations chose to use the systems they did. And so, hopefully, that will give you some insight with that on how some others are doing this today. And then, was lack of support, lack of knowledge, for this.

I think our speakers can certainly talk about how they gain some knowledge around this and how they made it happen in their facilities. And then, there are several people that have commented on the performance and so, we can, again, hear from some people who actually own these systems and have used them on how they're operating for them. Next slide.

Next question. So, thank you for your input on those questions. So, today, we have an esteemed panel of three speakers who are gonna talk to us about the applications. We're gonna start with Mike Walters from Salas O'Brien. He's gonna be talking about a couple of different locations and projects, followed by Trent Yunker with Western Wisconsin Health talking about his system that was installed.

And then, we're gonna hear from Ted Borer, from Princeton University, about what they're thinking and working on at that location. So, moving right along, Mike, are you ready to go?

Mike Walters: Yeah. Absolutely, Paul. Yeah. So, love to share our experience here today and we'll just kind of get right into it 'cause we've got a lot of content and, as we went through the questions there, I see lots of good thoughts and comments and things we all, I think, can speak to. So, next slide, please.

We'll go right into talking about two of our larger district-scale projects, one which is already complete – which is Ball State University – and the second, which is Miami University in Ohio. Next slide.

Ball State is a large system. As I mentioned, this project is completed already, and I was actually – as we were preparing for this presentation, kind of looking up, 'cause these large projects seem like you work on them for a long period of time – and, indeed, we did – and this project was completed – completely done – as much as eight years ago. The first phase of this was actually complete in 2010. So, this project and this system has been in operation for over a decade at this point. You can see here it is a complete campus conversion, and if we look at the map on the right side there, you can see two large, yellow blocks.

There's a large vertical heat exchanger on the North side of campus and then, a large vertical heat exchanger on the South side of campus, and two heat pump plants that are located immediately adjacent to each of those bore fields. In total, the system has almost 3,400 vertical bores. The top field is 400 feet in depth, and has 1,800 vertical bores in that field, and the bottom field has 1,583 heat exchangers in that field, and those are at a 500-foot depth. Paul's slide earlier showed the vertical depth and range pretty drastically – anywhere from shallow bores of 150 feet or so in depth to – we've done projects in excess of 2,000 feet in vertical depth. But the vast majority of our projects are shallower than 850 feet below the surface. Next slide, please.

Just sharing a little bit about the two district energy plants. Here – you can see here, the pictures of the – what we commonly refer to as heat pumps – really, these are large-scale chillers, centrifugal chillers or screw chillers that are used in these plants. There were two central plants here – not huge facilities – 12,000 square feet for the North plant; a little over 16,000 for the South plant – but putting large heat pump chillers in both of those facilities – so, in excess of 10,000 tons of capacity in both of those situations, and both of the plants were certified lead facilities at the time. If we go to the next slide, we'll see some more specific statistics about the scale of this conversion project.

So, this was an existing central that had coal-fired boilers and a steam distribution system, and it was completely converted to a ground source heat exchange system. So, that's an important piece to note. There's 47 buildings that had to be converted from steam connections to hot water systems and low-temperature hot water systems, and you can see here that we operate these buildings now at 140-degree supply hot water temperature. They were designed for 150-degree temperature, and we'll share a little bit about that. And then, relative to carbon production, this has been their largest project to date that has been part of their climate action plan to achieve carbon neutrality here.

So, they achieve 50,000 tons of carbon reduction on an annual basis from implementing this conversion project. And there's really two components that go into that. You can see at the bottom, there's a significant change in the energy use intensity for this campus. So, we went from 175 Kbtu per square foot per year to just over 100 after this project was completed, and that was due to eliminating the losses that exist in large-scale steam distribution systems and converting those systems to low-temperature hot water, and then, obviously, the efficiency that comes with using the heat pump instead of gas-fired boiler. So, if we go to the next slide...

I'll talk just briefly about the nexus of sort of temperature versus cost versus efficiency in these systems, and you can see a couple of other project names on this chart here. You can see Ball State was designed at 150. I said it operates at 140. But as you go lower and lower on the hot water temperature, the cost for doing the conversion frankly go up. You have more work that you have to do in the buildings to convert those to operate low-temperature hot water systems, but you get much higher efficiency from a heat pump perspective.

So, that's the constant pressure in these projects – is to find the right hot water supply temperature for the equipment you want to dispatch in the buildings you have and the existing systems that you have. Next slide here shows how we looked at Ball State's campus.

And you can see three campus maps, and what we did was we did hot water reset on the supply systems in the buildings to see what buildings show up in red or yellow on this map as buildings that have problems maintaining space temperature during very cold, ambient conditions at 180 degrees, at 150 degrees, and at 130 degrees. And you can see the 130-degree map shows us a lot of buildings start to fail at that supply temperature, and so, that's why the 150 temperature was selected to optimize the amount of – or minimize, even – the amount of capital investment that will be required in the buildings. This project, I should note, was completely done vertical bore fields. The energy stations and the building conversions were approximately $85 million in the 2010 through 2014 time frame. Next slide here will show you just briefly some information about Miami University in Ohio.

We can skip this cover slide and go to the next one right away just to keep on path here.

This is the central energy plant – one of the central energy plants that was developed as a part of this campus conversion, and if we look at the next slide, you'll see a complete campus map that shows a large distribution system that is completely a steam distribution system.

And the next slide shows what the process is that they're going through right now over a 15 or 16 year period to convert the campus to ground source heat exchange, add chiller plants, and add thermal storage to this system to optimize how the performance happens here. The next slide really tunnels into the geothermal plant itself and shows the energy profile in 2018 for this ground source heat exchange plant.

And you can see the sort of dark red and dark blue is the simultaneous heating and cooling load that that facility is able to meet, just with running the heat pumps themselves and not actually using the energy from a ground resource. And then, the lighter shades here are where the heat pumps need to go to the ground and acquire more energy either in the cooling side – they have to reject energy to the ground during heating mode; they need to pull that energy and push it into the building. And the really interesting thing is this next graph on the next slide that shows the coefficient of performance for this plant.

So, you can see – if you're thinking about a gas boiler or electric resistance heating, the COP would be approximately one. And during different periods of the year, this geo exchange plant is an extremely high-performance resource from this university, almost achieving a COP of eight in July where we're really having just an exceptional energy performance there. And if we look, on the next slide, across the different plants this campus operates, you see it comparing coefficients of performance on an annual basis.

You see the steam plant is below one. The chiller plant that has very efficient centrifugal chillers in it is a very high efficient resource for them, and then, the geo exchange plant, with 51 percent, provided the energy out of there for heating, and the other half for cooling is achieving that 5.1 COP. The next slide is perhaps the most interesting from a metrics and long-term performance of the current implementation of this conversion project where you see, again, a drastic reduction in energy use intensity.

You see, through 2020, we've gone from right over 165 Kbtu per square foot per year – in 2020, we were measuring somewhere around 85 to 90 range, and we expect that to continue to decline into the 70s as the rest of the project is implemented. You're seeing drastic savings in utility cost, drastic savings in carbon reduction, and really, just kind of an amazing amount of utility cost savings that this program has been able to generate – almost $80 million since the program started. So, that's just exceptional. And the next slide kind of shows how operating those plants with different COPs – what the cost comparison is for each of those plants.

So, it costs almost $6.30 per MMBtu to operate that steam plant versus the geo exchange plant, which is down in the $2.80 range. And that's related to labor cost savings. That's – commodity costs are certainly included in that operational number, and then, just all of the chemical treatment and other activities that have to occur in a steam plant versus a geo exchange plant to really operate. I have a few more slides I'll try to go through quickly. The next one is stepping out of the college and university space, and just very quickly showing an application of a vertical heat exchanger and much smaller heat pumps in a community residential development perspective.

So, what you're seeing here is a development that is almost 1,000 homes, and the blue – dark blue lines in there indicate where small vertical heat exchanges have been developed in the public road network throughout this facility. And this is an ambient blue that moves through this development, and heat pumps are in each one of the residential units and exchanging energy with that ambient loop, and eventually, with the ground. And this ambient loop is in series with all these buildings, as opposed to distributing a four pipe system through a campus or district energy kind of situation. Lots we could share about this project. I just wanted to put this here as another example of an application that's done very large, but not with monolithic bore fields, and in a much smaller sort of commercial or residential setting.

And finally, I wanted to make a couple of points related to air source heat pumps. The next slide will show you just a comparison of carbon emissions when you look at electricity versus gas in an air source heat pump scenario, and particularly looking at a greening of the grid scenario.

So, you have the current electric grid in the blue line, a 20 percent more efficient or less carbon intensive grid in the orange line, and the current gas activity you look at from a boiler perspective. So, you have the kilograms of CO_2 per btu of heating, and you can certainly see, as you go from the 35-degree inflection point on the current electric grid, if we continue to refine that and get more renewable electricity, you can operate air source heat pumps as low as 5 degrees Fahrenheit from outside air temperature and still be less carbon intensive than gas heating would be. If we look at the next slide, you'll see we're looking at air source heat pump efficiency, and this is back to some information Paul started with where it's all about the amount of lift you have to do and driving towards a lower supply hot water temperature.

So, you see the left axis there is the air source heat pump coefficient of performance, and the blue line, the lowest temperature hot water is, of course, the highest efficiency, because you're doing, essentially, less effort to create that utility. And then, the outside air temperature, as you go warmer and warmer, then the coefficient from the air source heat pump continue to improve. Last slide I have is just one more tunneling into this air source heat pump and cost efficiency and really looking at comparing air source heat pumps to a conventional steam plant.

And you can see here, again, about the outside air temperature, as that goes higher and higher, the air source heat pumps continue to get more and more competitive and begin to really beat the cost-effectiveness of operating a steam plant. So, certainly happy to answer some questions later, but I'd like to transition to the next speaker.

Paul Torcellini: All right. Thanks, Mike. I did want to make sure I got a little bit of your bio in there, which I neglected at the beginning of this. But Mike is a principal with the engineering firm, Salas O'Brien, and an adjunct professor at the University of Wisconsin Madison in the School of Civil Engineering. That was a great presentation.

Talked about a lot of the different pieces and just the planning and how you have to really think about sequencing through all this. I've seen that many of you have found the Q&A tab in Slido, and so, please, continue to put your questions in there. We've got lots of great questions coming in. We'll try to address as many as we can at the end of the presentations. Also, if there are questions there that you would like to give a thumbs up with, we'll try to prioritize the most popular questions at the top of the queue when we go through this.

So, please, kind of review those questions and indicate where your preferences are with that. And finally, a couple of other housekeeping points I would like to cover is that we will be recording this webinar and archiving it on the Better Buildings Solution Center. There will be a follow-up e-mail when the recording and slides are available. And so, if you do have any issues, you can certainly put something into the Q&A box on the Zoom panel, and it will go to our tech support team if you need any assistance there. So, let's, with that, move to our second speaker, who is Trent Yunker, who joined Western Wisconsin Health in 2013, and had spent the previous 12 years in the architecture fields of project manager.

And so, he brings a broad range of experience with design and construction and project management in health care. I notice that, on the questions that are coming up, that there's definitely some interest in health care, and people are eager to hear about what you're doing. So, with that, I'll turn the floor over to you.

Trent Yunker: Thank you, Paul. Thank you for the invitation. We're gonna switch gears here a little bit and look at things in a little smaller perspective. You can go to the next slide if you want.

So, we're from Western Wisconsin Health. We are a small, privately owned, critical access hospital. Our campus is 107 acres. You can go to the next slide again. Sorry.

We're gonna – I guess my goal today is to really – to get you – give a site overview, give a little bit overview of our system performance, and then, a really quick snapshot, I guess, of how it's performing today. As I said, we're a privately owned organization. We're a critical access hospital, rural health clinic, and wellness center under one roof. We have 107 acres. We developed about 35 of 'em for this project.

The project we're talking about today is a full-on replacement hospital. In 2012, we began initiative to replace our existing aging facility. Our choice to go with a sustainable or renewable energy source was really led, really, by our leadership's commitment to sustainability. It was balanced with, I guess, what was attainable for us in the cost – from a cost perspective – and this is a little bit of a snapshot of how we go there and what it looks like today. We employ 400 staff.

We're a LEED Silver Certified building, Energy Star rating of 91. You can go to the next slide, if you'd like.

Quick overview of our system. We have a horizontal geo exchange system. We have a loop field at 15 feet depth and 30-foot depth, 176 loops. We have a multi-stack brand heat recovery chiller, domestic water preheat system, which gives us the ability to preheat our water up to about 100 degrees prior to going into our domestic hot water system, and it also provides heating for our pool water. Around the building, we have VAV air handling systems with chill beams and some traditional fan coils as well.

All of our air handlers do have air side energy recovery, utilizing energy conservation wheels, and desiccant wheels for dehumidification, and we utilize in-floor radiant heat on all of our slab on gray areas around the perimeter of our building. You can go to the next slide.

This is a quick look at what our campus looks like. We really had a broad community vision when we chose this site, and really want to develop a campus that encompassed a succession of living and continuum of care. So, you can see our hospital is the bright white portion in the middle that's currently developed. Our geothermal exchange system is a lower portion in the lighter brown. It's about seven-eight acres.

And then, to the left of our building, we do have – the darker brown area is about six area planned for a future solar array. So, this building was really phase one in our long-term vision here for this campus. The other buildings and areas you see on this diagram are some retail and support space up in the top left, independent living, and assisted living and skilled nursing facilities would kind of complete that whole vision. You can go to the next slide.

And now, this is just a really quick look and a simple look at how our building is performing. In 2018 – 2017-2018 – after we settled in, we started tracking our annual energy consumption, and we're benchmarking this with a – using a benchmark from a hospital energy survey put on by firm out of the Milwaukee area. Includes about 130 hospitals – mostly the Great Lakes area. There are some sprinkled out there in the Eastern and Western and Southern parts of the country, but this is a look at our building. We're looking at 98-100,000 btus per square foot per year over the last couple of years. 2022 is coming along nicely.

On the month to month look, we're right on track with previous years. But that target – or mean – used on this, was the mean used from that energy survey. And in full disclosure, there's much larger facilities. We're on the smaller end of this square footage of those, and probably on the newer end, too. So, this is what we're looking at annually. You can go to the next slide.

Look at the past two and a half years of monthly energy consumption and btus per square foot. As you'd expect, we have the graph trending upwards and then, back downwards as we enter and leaving the heating season. You can go to the next slide.

This is an interesting one – total monthly gas consumption. We are not full on sustainable renewable energy. We do have gas-fired boilers that supplement our geo exchange system, and they are needed. Maybe one of the biggest lessons we learned in this whole process in operating this building is that our ground isn't as efficient as we had hoped. Water temperatures aren't sustained as long into the heating season as we'd like, and they don't come back as much as we'd like.

Our building is actually on the heating dominant side versus a cooling dominant side, which I think the engineering companies would tell you that's maybe not typical for health care – at least it wasn't typical in our building model that we generated here. But we use gas-fired boilers to supplement a little bit during the heating season, and if you were flip this graph upside down, our ground water temperature actually trends the same direction as this. So, kind of gives you an idea of the efficiency of our system right now. You can go to the next slide.

Total monthly electric consumption. This, I guess, is typical of what we'd expect, but different than maybe a system that has rooftop chillers that fire up during the summer. And you see those spikes and valleys for electric consumption. You can go to the next slide.

That's a quick one for today. I just wanted to give you a real quick look at how our system is performing. Some of the advantages we've seen are operating costs. Utility costs play a large role in that, but if we can keep our consumption down, then utility costs should follow. The other thing that we've noted in operations here is that water flow and water temperature and water chemistry are really paramount for our system to be operating properly.

I look forward to any questions. Hopefully, I can answer them, but transition into the next presenter and thank you for the time.

Paul Torcellini: Okay. Thanks, Trent. That was great. Just a quick reminder that if you do have questions, to add them to Slido – Slido.com. The hashtag is DOE, and we look forward to trying to answer as many of those questions as we can.

We're getting a lot of great questions and so, we will address what we can at the end of the presentation. So, our final speaker today is Ted Borer, and Ted is with Princeton University – Energy Plant Director, actively involved in the campus energy and carbon emissions reduction effort and strategic plans. And he has been involved with this industry for 36 years, speaks regularly on these topics, and we look forward to hearing what you're doing at Princeton.

Ted Borer: Hey, Paul. Thanks a lot. As Paul said, I'm a total nerd for this stuff. I absolutely love it. Next slide.

What I'd like to do is walk you through where we are as an institution, and then, point to where we're going, which I think is really more of interest today. So, next slide.

Here's the problem that's on my desk. It's on Paul's, it's on Trent's, it's on Mike's, and ideally, it's probably on yours, too. In a lot of words, this says we need to save the planet, but we can't make up the rules right now, and we still have to keep the core business going. In the energy plant, we're a support function. We're not core business.

So, we need to leave the education, the research. And the other thing that I think Paul underscored early is – we need to do this with financial stewardship. We need to spend our money wisely. Because even if some of these institutions could throw lots of money and eliminate the carbon footprint, if we don't do it in a way that's financially responsible, nobody else will follow us. So, we can't be impactful unless we pencil it out and say, "In fact, what we're doing is the lowest lifecycle cost for the institution." And we can talk about that later. Next slide, please.

The university has about nine million square feet – nine and a half million square feet. We're growing rapidly. By far, as the other speakers alluded, the research is the most energy intense. So, a lot of reasons the energy plant is really in service to the research buildings – because of the high reliability needs, because the energy intensity – and the other buildings come along with. Next slide, please.

For those who want the numbers, top right-hand corner shows that we use about 27 million megawatts on the very hottest day of the summer, the peak of the day. I can make 15 megawatts with a gas turbine, a jet engine, which is what I think of as controllable power generation, and then, we have another 16 and a half megawatts of solar. So, in the utility industry, we talk about this as a very high penetration of renewable energy, which the university's gonna demonstrate how that can work well having a very high amount of renewable energy and only supplementing it – kind of like what I think Trent was saying – only supplementing it with combustion or fossil fuels when absolutely necessary. In terms of heating in the campus, we need 240 million pounds of steam an hour. We do that with the exhaust heat from the gas turbine of from auxiliary boilers, primarily burning natural gas – again, diesel fuel as backup.

And in terms of chilled water, we can make chilled water with steam-driven chillers or with electric-drive chillers. We have about half/half in terms of our needs so, most days, when it's not the peak demand day, we have a choice. Do we want to burn natural gas, make steam, and run a steam-driven chiller, or do we want to purchase electricity or generate electricity and run an electric-driven chiller? We also have energy storage – not in the form of batteries, but in the form of daily thermal storage. It's a chilled water thermal storage tank, and what we do is we buy power when it's very inexpensive, we cool off two and a half million gallons worth of water, and then, we can shut off our electric chillers and shut off our electric cooling towers and simply deliver water from this tank for anywhere from 4 to 10 hours, and we can deliver up to two thirds of our peak cooling demand on the very hottest day for 4 hours.

That thermal storage tank looks an awful lot like 40 megawatt hours of electric storage, and functionally, we use it the same way. Next slide.

The co-generation system is illustrated here – gas turbine on the left; spinning an electric generator on the right. It's about one-third efficient. If I put a unit of fuel in, you get about one-third of that fuel energy out as useful electricity, and so, it would be very important to operate that in what we call "simple cycle mode". But, if we take the hot exhaust gas that comes out at 1800 Fahrenheit, we can run that exhaust gas through a boiler and we can make steam, and the overall process shown on this slide is about 85 percent efficient – sometimes down around 75 and sometimes higher. So, the overall co-generation process is 75 percent or 80 percent efficient, and I think one of the previous speakers mentioned – that's not unusual. That's about right for plants of this of this vintage and for boilers. Next slide.

Here's our chilled water with thermal storage. So, what we do is run on the chiller and we reject heat through a cooling tower back to the environment, and we can cool off two and a half million gallons of water and then, the thermal storage decouples the time of production from the time of need. So, if the chiller – or really, I should say when the chiller fails or when the cooling tower fails, the operator can just turn up a variable frequency drive on a pump and they can pump water out of the chilled water thermal storage tank and delivery cooling to the campus, and the researchers and the other customers on campus have no idea that there was a problem in the plant. So, we decoupled the problems from the plant from our customers, and also, we now have the opportunity, on a good day, to buy power when it's cheapest and avoid the purchase of power when it's most expensive. Next slide.

I think the energy plant as a big energy conversion box. I buy electricity and natural gas and liquid fuels, and I get a gift from the universe of solar – of sunshine – and we convert each of those inputs into electricity and steam and chilled water. Next slide.

Our goal was to get to carbon neutrality. Our stated goal is get to carbon neutrality by 2046. Currently, we're responsible for about 100,000 metric tons of carbon emissions a year, and we know that we're not just gonna count on doing nothing, nothing, nothing, nothing, and then, magic in the very last year. We're gonna drive towards a linear downward slope from today to 2046, and the bulk of that will be converting buildings from steam heating and steam hot water to all hot water district energy. Then we're gonna – in the green triangle – we're gonna need to power all of that hot water district energy with renewable electric input. I expect we're gonna drive our combustion down and down and down, but we won't get to zero combustion.

Right now, we burn natural gas maybe 8,500 hours a year. I expect to, very quickly, go from 8,000 to 4,000 to 2,000, and maybe 1,000 hours of combustion, and eventually, we'll have to do that with biodiesel or some other renewable fuel. Next slide.

This is walking you from the building all the way out to the energy source in terms of the different things that we're touching on campus to reduce our carbon footprint. So, in the existing buildings, we're gonna have to retrofit the building, tighten it up in a lot of cases – air sealing insulation, lights changing – very classic work – to tighten up each of the building envelopes. Any new building will be a high-performance envelope, and to the extent we can, we're gonna try to meet a – what's called a "passive house" design standard. All new buildings and all major retrofits will be hot water heating. The next thing we'll do – or right now, we are actually replacing our district steam system with a district hot water system, but obviously, we need to install 13 miles of hot water pipe before we rip out 13 miles of steam pipe. Or at least we need to have each building operating on hot water before we can remove the steam.

So, it's quite a ballet that we're doing on campus right now. We have to create – and in fact, we're creating two new electric power heat pump facilities – one on the main campus, and one on a satellite campus that we're building in a Greenfield effort. We will add both hot and cold-water thermal storage for this daily – buy low and deliver to our customers when energy's valuable – and that daily reliability and resilience that thermal storage adds, and then, we will create seasonable energy storage. I have a lot more heat removal I need to do in the summer, and more heat delivery that I need to do in the winter. So, we will store, as Paul mentioned, in geo exchange well fields.

We'll capture the heat from the summer, store it in the well fields during the summer and late summer, and then, we will deliver it to the campus late in the year or when it's cold out. We're gonna bolt solar photovoltaic to anything that doesn't move on campus, and then – that won't satisfy all our electric needs so, we'll buy electric renewable energy from off campus. Next slide.

We're needing to replace the steam system that's more than 100 years old and so, rather than committing to another century of steam heating, we're going to move to hot water heating, which is many, many times more efficient. Next slide.

Right now, on the right, we're adding heat by burning stuff in boilers and delivering heat to campus, and on the left, we're adding energy and we're removing heat from campus and throwing it away through cooling towers. So, what we're gonna do is combine those two – next slide – using heat pumps.

We will pull heat out of the chilled water system and deliver it to the hot water system. You see there's no longer a cooling tower, and you see that there's no longer the combustion process in the boiler. So, as the others alluded, probably five to six times more efficient through the coefficient of performance of the heat pumps. Next slide.

You've seen this idea previously, but the red is heat delivery to the campus during the winter; the blue is heat removal from the campus in the summer. You can see a nice match in the shoulder months, and you can see that I need to capture heat during the summer and store it in geo exchange and then deliver it maybe six months later, extracting that heat from the ground, and delivering it to the campus in the winter. Next slide.

You can see an architect's rendering of the plant. We're actually framed out, the roof is on. It's not yet populated with the equipment, and you can see the hot and the cold thermal storage tanks in the background. Next slide.

And you can see that, as I said, we're decorating anything that stands still on campus. Parking decks, flat surface lots, a few large fields. We're have about 60 acres of solar PV and some building tops. I think that's where I want to land it, and we'll move on back to Paul and then, on to some questions.

Paul Torcellini: Okay. Thanks, Ted. Yes. So, continue to kind of upload questions on Slido. We've got about 10 minutes here for questions, and let me start with the panel on how are you paying for these systems?

Are they internal budgets? Are you growing it on trees? Grants? Third-party ownership and management of equipment? What are the strategies out there you're using?

Mike Walters: I guess I'll offer a couple of quick comments – specific to Ball State and Miami. Those are both essentially public funded institutions. So, the states paid for those systems to be implemented. At Ball State, there was actually a DOE grant for $5 million. So, I don't know if you knew that, Paul, or not, but that was part of that project back in the day.

A lot of the work in Miami – it was all funded internally, but it was funded as part of regular processes to upgrade and maintain buildings or upgrade facilities at the end of their useful life. So, they waited, as they were turning over their dormitory facilities, to upgrade those to more modern facilities. They did the conversion work in those buildings as part of those projects so that was an incremental cost to the, essentially, the utility side of the equation. But we are seeing, certainly, third-party providers with very much interest to get into this space and provide funding resources to institutional campuses. That's a choice that every campus needs to make or not make.

Ted, I'm sure you have some perspectives on that.

Ted Borer: Yep. So, I'll take off where Mike left off. We are private and self-funded for a lot of these projects. For the solar, we're using a power purchase agreement model where somebody else uses their money. They bolt their stuff to our property, and then, we guarantee that we'll buy the output from the solar.

In terms of the steam – I already mentioned – we have a lot of deferred maintenance. The steam pipes that we're running – many were built before the first world war. They're more than a century old. We need to renew those. We'd be foolish to replace in kind.

We want to replace with the best available technology, which is district hot water. That is self-funded, and we've established an internal fund and – I won't go into the details of that, but that's looking at the lifecycle cost. We've determined that the lifecycle investment of a hot water system is gonna put us in much better shape than if we had continued with the steam model.

Paul Torcellini: All right. Trent, do you want to talk about how yours are financed?

Trent Yunker: Yeah. So, our project was through some subsidies – renewable energy subsidies, state and federal – and then, privately funded. We went through major fundraising efforts to make our project a reality. So, a lot of local support on a smaller scale here for Western Wisconsin Health. And, to mirror Ted's comments, our solar array is – we're working on it currently, and it's gonna be a power purchase agreement.

Ted Borer: I want to respond to one quick question. In terms of the solar renewable energy assets, in New Jersey, I can sell the green tags. We have sold the green tags from our first four and half megawatt field up til now. We're gonna begin retiring those. So, to date, I've made no carbon footprint reduction claim associated with any of the green tags that we've sold.

We count for that at utility emissions rates, and we're gonna do that going forward, unless we are – and until such time – as we're retiring those rights.

Paul Torcellini: Okay. So, a question, I think, specifically for Mike – others can chime in as well – the question is "The Ball Street project was completed 10 years ago. Why do you think this type of central plan conversion has not been widely copied since then?"

Mike Walters: Well, I was trying to wear out my fingers typing back some answers to a bunch of questions while Trent and Ted were talking, but I actually do think it's being widely copied. We have – we often have people reach out to us and say, "Hey, what else can we learn about the Ball State project? We're thinking about doing that ourselves." If I were to present the scale of the kinds of projects we're working on currently, it's coast to coast from Canada through the Mexican border. We probably have three or four dozen projects of scale like this that are either in various stages of being completed or planned or in fundraising mode, and that's in all geographies of the country, all climate zones.

I think it is the topic that we get called about and that we see the most requests for proposals and study work out in the industry right now.

Ted Borer: Well, I'll jump in and say – a lot of my peers at the international district energy association I meet with – pretty much everybody who's got a big campus is moving this direction. I'd be surprised if any of my major peers are doing otherwise, but it is typically somebody who anticipates their organization/institution is gonna be there for a while. We have relatively longer payback periods, but many of our institutions are gonna be here for decades ahead, and this is, by far, the best long-term strategy.

Paul Torcellini: So, Trent, do –

Mike Walters: I will say this quickly, Paul, that it is not an easy planning effort. It is not an easy project to gestate through the decision-making process inside of an existing institution or campus or even through a new development process. So, Ted said the lifecycle cost analysis work needs to be baked into this process, and you're looking at 30 modeling time frames or longer, and you have to really get into a lot of weeds. You have to get into your chemical treatment costs, your deferred maintenance program, your staffing needs, the commodity forecast – what's gonna happen in regulatory markets relative to the carbon incentive programs. There's a broad array.

And I do think that's one of the things that slows the adoption of this and slows the program of why aren't there 15 more projects like Ball State that are already done – 'cause it's pretty difficult.

Ted Borer: I'll throw in one more thing to Mike's comment – there are tremendous water savings with this that most people do not realize, and for states that are drying out or locations that are fighting over water – this is a really big deal to implement this, and I think a lot of people don't realize that yet.

Paul Torcellini: Trent, do you want to talk about some of the replication potential here?

Trent Yunker: I don't know if I have a good answer for that Ted or Paul.

Paul Torcellini: Okay. That's fine. Well, we'll move on here. I do like – Mike talked – well, all the speakers talked about the planning. I do like the graphics on the different temperature regimes for the buildings that will and won't work and would certainly like to encourage listeners – as you're doing any set of renovation or maintenance, really think about how you can lower the temperature of the water that the building needs and kind of being prepared to move in this direction, even if that means you're still using some kind of fossil fuel. In terms of the efficiency, looking at what those building loads and how much those pieces of equipment are being used is a first good step here to take in terms of long-term planning.

And I think one of the messages is – it is long-term. We did have a question – I know, Ted, you mentioned about aging steam lines and having to replace steam lines. There was a question/comment about needing to replace steam lines, and in 30 years, are we gonna have to replace all these geothermal lines? So, what kind of longevity – talk a little bit about the longevity of what you're expecting out of these systems.

Ted Borer: Yeah. I think Trent and Mike will echo this, but in the utility business, we really think in terms of a half century to a century investment. So, the steam lines that were put in before the first world war are still lasting. They're still working. But we really do need to replace them at some point.

What we're building/designing today – we're really planning for at least a 50 – and I really expect 75 to 100 year life – out of what we're installing. So, this is a – it's a once in a century type of event.

Mike Walters: I feel the same way, Ted, yes. Certainly, all of the horizontal infrastructure and the vertical heat exchanger – that is a many decades useful life kind of investment, and there's – I would not be surprised at all if those were hundred-year assets for sure.

Ted Borer: And we've demonstrated that with the stewardship of our existing system.

Mike Walters: Right.

Paul Torcellini: Okay. So, there are definitely lots of other questions related to maintenance and transition of maintenance which I don't think we're gonna have a chance to get to unless Trent, if you want to talk a little bit about maintenance on yours? Give me about one minute here.

Trent Yunker: Sure. Yeah. Biggest maintenance items to consider on ours has been water chemistry, and we are seeing our strainers plug up a little more than we'd like to. We're looking at adding some bypass functions to allow more serviceability to those types of systems. But water chemistry tends to be our biggest challenge right now, and then also, just from the heating and cooling of the water – and mostly on our hot water side of our system – but then, also, when we see those times in shoulder seasons of simultaneous heating and cooling and our geo field – our geo pumps turn off and it becomes stagnant, and then, they fire back up again.

So, that continuous flow of water should be considered, and maybe even burn a little bit more electricity just keeping that water moving to keep the chemicals circulating the chemistry in balance. So, really, from us, that's the biggest one. And I should note – we do use 100 percent water system here, too. We don't have any glycol. Maybe odd for Wisconsin, but we do.

Paul Torcellini: All right. Well, I want to thank all of our speakers as we wrap this up. This is part of the 2022 Better Buildings Summer Webinar series, and as you can see, we've got a great line of presentations. The questions for this were great – very in depth – so, I encourage you to join us for some of our other webinars. You can visit the Better Building Solution Center to learn more and to register.

The next webinar is going to be on June 21st, and it's *Industrial Demand Response,* and so, you can join this webinar and learn about the Better Plants program and develop guidance around demand response for industrial partners. I'm sure there's also things to learn here about commercial – especially the large-scale commercial projects. I also want to highlight the DOE release of the annual report with the key findings updates and metrics from the Better Buildings Initiative. And so, you can visit the Better Buildings Solution Center to explore the 2022 progress report to learn about how DOE and the partners are working towards a more energy efficient future. And so, with that, we are at the top of the hour, and I'd like to thank everybody for coming, and I'd like to especially thank our panelists.

And you can reach out to them if you had follow on questions, and thank you for attending today's webinar.

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