Crystal McDonald: Hello. I'm Crystal McDonald with the US Department of Energy's Better Buildings Initiative. I'd like to welcome you to the November edition of the Better Buildings webinar series. In this series we profile the best practices of Better Buildings Challenge and Alliance partners and other organizations working to improve energy efficiency in buildings.

We're curious about who's joining us today, and so we have two poll questions and we'd greatly appreciate your response. Okay. So we'll have our first poll question. What best describes your job function? Please respond to facility planner or manager, administrator or teacher, architect or designer, engineer or contractor, or other.

Okay. Do we have responses yet? Fantastic. Thank you. So I see the majority of our audience has identified as other, engineer, or contractor. Okay. Great. Let's move onto the next question.

What best describes your experience with LED lighting in classrooms? Good question. None or very limited experience, some experience with pilot installation, have installed LEDs in all classrooms in at least one school, or not applicable.

All right. Let's see what our response is. Wonderful. So I see the majority has had some experience with LEDs. Well, thank you for your responses today, and we welcome you to our webinar here. We thank everyone for your participation.

Better Buildings launched in 2011 with the goal of dramatically improving the energy efficiency in commercial, industrial, and residential sectors by 20 percent over the next decade. Through Better Buildings, DOE supports the effective use of financing, corporate leadership, state and local actions, workforce development, and efforts to deliver best information to the marketplace about the value of energy efficiency.

Here is a guide to the Better Buildings ecosystem. Within each bullet listed here, there's a whole team behind it working on a robust program. We break it out into four pillars with the goal of transforming the market and accelerating investment in energy efficiency. Today we will focus on the top right quarter of the graphic in the middle, delivering better information and making energy efficient investment easier.

Why are we doing this in the K12 sector? Schools are the third-largest energy consumer in the commercial buildings category.

Utility expenses in schools are second only to personnel and supplies. More importantly, over 50 million of American students spend about 200 days in a year inside buildings where the environment should be optimized for learning, comfort, safety, and efficiency.

Today we'll take a look at the use of technologies that may be becoming an arrow in the energy efficiency quiver for schools. We'll hear first from Tracy Beeson with the Pacific Northwest National Laboratory, who will describe one of our newest resources, the K12 lighting toolkit, which offers comprehensive guidance for K12 schools along the review of the newest lighting technology and strategies for classroom optimization to help school energy managers use the best available applications for their schools.

Next, we'll hear from Bob Davis, also with Pacific Northwest National Laboratory, who will discuss tunable LED lighting in the classroom and the results of two pilot studies performed in Texas and California. This presentation is designed to inform our stakeholders with their decision making when it comes to lighting upgrades, which is often considered low-hanging fruit on the path to energy efficiency.

So let me introduce our presenters. Tracy Beeson joined PNNL earning an MS in architectural sciences with a concentration in lighting from Rensselaer Polytechnic Institute and became lighting certified by the National Council on Qualifications for the Lighting Professions in 2008.

Ms. Beeson has a considerable knowledge base of general lighting applications and technologies and has experience in field demonstrations involving lighting measurement protocols, and establishing best lighting practices to improve energy efficiency from various entities. She also contributed to the development of the National Energy Standard for ASHRAE 90.1-2010.

More recently, she has been overseeing the lighting testing efforts for the solid state lighting program and has been working to coordinate the simplification of data transfer between testing labs and various voluntary and research programs. She is passionate about research and implementation of day lighting and advanced lighting controls while reducing lighting energy consumption without compromising lighting quality of the visual environment.

Our next panelist is Bob Davis, who is a senior staff lighting engineer at Pacific Northwest National Laboratory, where his responsibilities include serving as technical director of the solid state lighting program and leading several human factors research efforts. He has been a faculty member at RPI's lighting research center and an engineering at the University of Colorado at Boulder.

His experience includes working in engineering and marketing at a lamp manufacturer and leading the product development and engineering team in a luminaire manufacturer. He has degrees in architectural engineering and a PhD in cognitive psychology, and is a fellow of the Illuminating Engineering Society.

Thanks to you both for joining us today. Before we get started with our presentations, I want to remind our audience that we will hold questions until the end of the hour. Please send any questions through the chat box or your webinar screen throughout the session today and we'll try to get to as many of them as we can. The session will be archived and posted in the web for your reference.

So to start us off, I'll just hand over the mic to Tracy. So Tracy, take it away.

Tracy Beeson: Thank you so much, Crystal. Such a pleasure to be here and be talking to all of you today. We're going to be going through the outline here. Today is the overview of the new K through 12 lighting toolkit, which is primarily what I will be covering.

And then we're going to transition over to Bob, and he'll discuss some of the science behind tunable LED lighting and why it's so important, specifically in schools. And then you'll get quite a great overview on some different pilot studies that have been underway with different tunable LED lighting in K through 12 classrooms. So next slide, please.

So the K through 12 lighting toolkit will be available through the Better Buildings Alliance Solution Center. You can see the URL listed here on this slide, but at the end of the presentation, we'll also provide a slide of resources that we discussed during this presentation. So you'll be able to access that all later on, as well.

The Solution Center provides an abundance of resources. There are various different avenues to determine what solutions could be useful for the application or the challenges that you are up against in your specific project. You're able to search by the technology that you're considering. And the Solution Center provides various

different avenues for helping to overcome different barriers associated with those energy efficiency technologies that are being considered, and helps point you in the direction of various promising solutions.

So you can search by your building size, by the location of your building, by the sector or type of building that is under consideration for upgrades or energy efficiency solutions. And so this URL, this website is a wonderful tool that should definitely be utilized for helping nail down some different solutions that could be useful to you.

Financial options and planning efforts for planning for finances is also something that is highlighted within the tool. And there are additionally a lot of successful projects that are showcased. So there are real projects from real people who have faced the challenges and overcome and been able to implement successful energy efficiency solutions. And so that's always a really great way to serve as inspiration and validate some of the things that you might be considering as far as energy efficiency in your building.

There are also analysis tools available. And then one of the focuses of the Better Buildings Solution Center are accelerators. And accelerators are intensely focused efforts which are designed around specific challenges. And all of the different ways that you can mitigate the barriers when you are undertaking these different challenges in implementing energy efficiency in your building.

And then, of course, toolkits are – this is what we're going to be talking about primarily today, which is – a compilation of resources that's designed to overcome those barriers that the accelerators will highlight and work towards mitigating. And the toolkits are also very specific to a specific building type or a specific sector type.

And so we will get into the next slide, where we're going to talk about the K through 12 lighting toolkit and why it is so important to have a toolkit specific for schools. We were identifying resources for the K through 12 school setting. It's, of course, important to remember that there are needs that occur in schools for the users – end users – of the schools that are very specific.

Schools have a dynamic use of the various spaces. There are maintenance challenges associated with the school setting as far as scheduling of upgrades, time of use for the various space types. And then, of course, in order to address a lot of the challenges we

need to understand which challenges are specific to the school setting. And, of course, dimming and controlled is something that can be difficult to implement, but it's very important for all the dynamic uses of the K through 12 classroom and the other spaces that exist in school settings.

And then we're also going to be very much addressing some of the new science that is being heavily researched right now – as I'm sure many of you are aware – of the different issues and the different options that are available and being researched at this time regarding light and health.

And one of the very important aspects of the K through 12 setting is providing a healthy environment for those end users. And so understanding that new science is going to be a very important component when it comes to determining good quality energy efficiency upgrades. And, of course, financing options are always something to be considered as we're implementing new energy efficiency technologies. So we can go onto the next slide, please.

So with all of the resources and so much information available, of course it can be challenging to know where to start. So that's where the K through 12 toolkit comes in. There are a lot of different types of resources available through the Better Buildings Solution Center. And a lot of them apply to the K through 12 setting.

But after having reviewed all of the needs specific to the classroom setting and the school building sector type, what we've done is we've compiled a whole list of resources that will be available through the lighting toolkit. And I'm going to go into detail about each one of these and what you can expect from these different types of resources. But this is essentially the list of the types of resources that we have compiled for you for your use in the K through 12 toolkit.

Case studies, design guides. There are fact sheets and more technical reports, as well as model specifications, some videos, and webinars; including this one, once it's posted online in the Solutions site. And so next slide, please.

Okay. So DOE has a lot of great resources and you'll see that a lot of these resources come from the work that the Better Buildings Alliance has done, as well as the solid state lighting program. But additionally there are many other organizations that are doing and providing a lot of resources for upgrading to energy efficiency in

lighting. And so we've included anything that's relevant and pertinent to the K through 12 setting.

So when you're looking at case studies, these are great – of course they're great. But they are really wonderful ways in which you can see how other tangible challenges and barriers have been overcome in specific buildings. And so case studies will highlight actual projects and they'll go into detail about the different challenges that were addressed, and then the specific solutions that were applied. Next slide, please.

Design guides are somewhat similar to case studies in that they are challenge-focused. But they can help drill down to the specific needs of a state. And then they can really help identify tailored solutions and approaches. These are design guides are application-specific because the various space types and various challenges are sometimes associated with specific spaces and applications within the K through 12 setting. And design guides really address those nuanced challenges for each space type. Next slide, please.

Fact sheets are also application-specific. They tend to be a compilation of potential issues and provide multiple paths to solutions. And they are used more primarily in stages of determining the project's scope and of high-level application-specific guidance when different space types or different solutions are being considered. They can really help you to identify the questions that should be asked in those early stages. Next slide, please.

This specific fact sheet, upgrading troffer luminaires to LEDs, isn't necessarily specific to just K through 12 schools. But there are some resources that are still applicable to the majority of spaces within these types of buildings, that that application is so prolific that we've included the different fact sheets and reports that apply to those K through 12 space types, even though it's not necessarily application-specific.

That's why there's a lot of design guides and case studies that drill down more to the very specific details. And so, yeah, this fact sheet will have the link for this one specifically as this is a very prolific application type within the K through 12 setting. Next, please.

So reports are a much more technical level of details. They are for those that are truly wanting to understand the science between the recommendations and the decisions that want to be made. They're

research-oriented and provide a great deal of details regarding the data and the reasoning behind most of the suggestions. And facts, of course, to support why we're considering investing in the upgrade.

And they can really help leverage the higher-level decision making when it's a larger discussion as to whether or not it's important. The reports can really help support the stand that energy efficiency upgrades are important and they can provide you lots of detail on why. So next slide.

There's a couple different model specifications that have been developed through the Better Buildings Alliance. And these specs are really, truly where the rubber hits the road. They're technical documents, and they set high standards.

There's a lot of products available on the market, and one of the things that these specifications do is help the spec fires, the engineer, or the designers, to understand what level of performance is acceptable and should be strived for based on where the technology is currently and what the general performance characteristics are of a specific luminaire or lighting type.

And so it's important to consider the performance characteristic as far as color and light output, any maintenance concerns. And these specifications really just provide that very technical level of thinking to ensure that performance is not compromised.

And then the last slide here about the K through 12 toolkit resources – or, I'm sorry. There' actually two more. This one is discussing videos. So videos are – we've all seen videos on YouTube. They summarize projects in a much more visual way. We do have a couple different video resources that are available or will be available on the K through 12 toolkit, which can be very easily shared.

And they're generally less technical. They can provide a very accessible way to share and highlight some of the reasoning for energy efficiency upgrades to various stakeholders. So this can be a really good method of distributing some information in a less technical fashion. So next slide, please.

And webinars, of course, like the one we're doing today here, can be very useful because they summarize – they pull together – a lot of different information from a lot of different areas and provide

that information to you in an easy to access, and pretty straightforward format.

There's a lot of dynamic discussion during the webinars with the feedback from the audience, which is great. We look forward to your questions. And, of course, they can provide additional resources, things to consider, and avenues for additional exploration. And so this webinar will be recorded and the link will be available through the Better Buildings K through 12 toolkit once it is also accessible. And so this will be something that you can access later on, or share with others at a later date.

So I think we'll move onto the next slide here, and Bob Davis will be talking to you all about some pilot studies. For the past year or so there's been some color tuning studies that have been underway in classrooms. And so I will pass the mic over to Bob, and we'll get to hear more details on that.

Robert Davis: Thank you, Tracy. And thank you, Crystal, for the introduction earlier. And thanks, everyone, for joining in. Tracy and I are in Pacific Time, so those of you out here on the West Coast with us, thanks for taking some of your lunch hour. And for those of you in other time zones, thanks for giving us part of your day.

We really have two goals; one that we laid out to start. One was to review the new lighting toolkit. I think it's going to be an exciting toolkit for those of you working in schools and school facilities. And as Tracy mentioned, it features a lot of work that's come through DOE, but also we tried to pull in resources from other groups who have really good educational documents and resources that you can access. So that should be going live shortly. And so hopefully you'll find lots of good information there.

As Tracy said, I'm going to tell you about some specific projects that we've been involved with here at PNNL through the DOE's solid state lighting program. Before I do that, though, we did want to get some quick feedback from you about the nature of the tools that Tracy talked about and which of those sorts of things you've found useful in the past.

And so if you can interrupt what you're doing quickly and answer another tool question here, which tools from Better Buildings or other sources have you found the most useful? And then we have a list of some of the things Tracy talked about: case studies and design guides, fact sheets, technical reports, model specs, videos and webinars. Please select which ones you found the most useful.

And if we can see those results whenever they're ready… All right. Now we let you pick more than one, so if you're looking at these saying, "Wait. That's more than 100 percent," like I just did, it's because you could pick more than one. But you can see graphically case studies and design guides are really strong tools. Videos and webinars, that's good to know. So very good. Thank you for that.

And so if we can move onto the next slide, I wanted to give some general background about energy efficiency lighting leading to LEDs before we talk about specific case studies. So most of you online, I'm sure, have experience with other lighting technologies. In fact, I think we had 33 percent that said you really don't have a lot of experience yet with LED lighting, and other 17 percent just through some pilot studies. So I'm sure most of you in your schools fluorescent has been the main energy efficiency technology you've used inside the buildings. Outside probably some HID lighting.

And it seemed like for a lot of us – and I got started in the lighting industry back in the early 1980s, growing up with fluorescent lighting. And it always seemed like we knew we could save energy. We knew we could save money. There was always this list of buts that came with the technology, right?

But we couldn't quite get the color quality that were used to from things like incandescent. It was difficult to dim, or at least expensive to dim, right? It was available, but it wasn't easy to implement. And in some cases back – and this dates me right back to the magnetic ballast days – we had flickering issues sometimes even with modern technologies in dimming. You could get some noise.

Warm-up time, even with fluorescent. I make the joke that I'm not a good energy efficiency person when I get in the hotel, because I have to turn the bathroom light on way before I go into the bathroom to let the compact fluorescents warm up enough. And of course, with HID, that's even a worse issue.

And then this bullet, static color. By static, I mean you can't change the color. Now, the slide here shows some different colors of fluorescent lamps. So you certainly could get different color, different spectrum of light. But you had to replace the lamp, replace the bulb, in order to change the spectrum. But when you bought a product it had its own color and you couldn't change that. And then, of course, these products have mercury, and so it created some hazardous waste.

On the next slide we'll talk about LED lighting. Now, there's no doubt that with LED lighting we know we can save energy. We know we can save money. And there are some buts. I won't pretend that there aren't some buts that come with it.

But I think the strong message for us in our experience is that a lot of people are using LED to save energy and money and they're finding other benefits. With LED you can get much better control over the color, and so you can actually get color quality that's as good or better than what we were used to before. Dimming is sort of inherent with LEDs, so they're kind of dimmable right out of the box. No warm-up needed. Tunable color.

I will talk a lot about that, that a great thing about LEDs is that you can change the spectrum of light from one fixture. You don't have to have different bulbs around in order to change color. And we'll talk about why you might want to do that. No mercury.

And then I put on the bottom here this question. Is is better for learning? I think what we're finding in working with schools is that this combination of easier to control, the chance to change the spectrum, some of these other issues we mentioned not only help you save energy and money, but do they create opportunities to improve the learning environment?

So on the next slide we'll start to think a little bit about what is this tunable lighting? What do we mean by tunable LED lighting? In the fluorescent world – and the picture here is of a classroom in one of the schools we studied in Folsom, California. The fluorescent system that was their existing classroom system. A lot of fixtures. They were trying to get a lot of light on the walls and on the perimeter. Most classrooms use the walls heavily.

And on the right side of this slide – if you're not familiar with it – this is what's called a spectral power distribution. So it's showing the spectrum of light that the fluorescent system produces in this classroom: 3,800 K, 3,800 Kelvin is the way we describe the color of light, the apparent color from warm to cool. So higher numbers mean it's cooler light. Lower numbers mean it's warmer light.

The graph itself, I'll just give a quick intro for those of you who may not be real familiar with these. Some of you, I'm sure, are. But this is showing the wavelengths of light that the fluorescent lighting system in this room produces. Now, we actually measured

this. So this is not anything that came from the manufacturer. This is us getting in the room with our meters.

And so from the left you see the numbers 360, 410, 460? That's the wavelength of light in nanometers. And the shorter wavelengths are what we call the blue and the violet ends. So down there at 360, to 410, to 460 is sort of the blue, violet. And then as you move up through the middle, you get up to green, blue-green, and then yellow.

And so that big peak you see in the fluorescent just ahead of 560 nanometers, most of our lighting products try to have a big peak there because that's what counts the most for lumens. Your visual sensitivity for daytime viewing as we would have in schools is the most sensitive at 555 nanometers. And that's the way the lumen is defined.

And so most lighting systems are designed to try to produce a lot of that green-yellow light because that's what makes the eyes work well for vision. And then you also want some of the longer wavelengths, which is moving into the orange and red as you move out there to 600 nanometers and 650. That's getting the orange and red wavelengths of light.

And so with that fluorescent system, this is the spectrum you get. Sometimes you get mixed spectra because the person replacing the fluorescent lamps might have gotten a different one, right? So we've all seen that. And in fact this school certainly had that, where there were different colors of fluorescent lamps in some of the individual luminaires. But that's not at all tunable. You don't have any ability to change the spectrum of light from that fluorescent system.

On the next slide, we show an example of tunable LED lighting. And this is just to describe it. We'll come back to these school pictures in more detail. But what do we mean by tunable LED lighting? Tunable usually means two things. And you see the line at the bottom of this slide. It's the ability to vary the spectrum and the intensity of light, right?

We're all familiar with tuning the intensity through dimming. And so these systems allow you to dim, certainly to change the intensity of light. But the thing that is exciting about LEDs for those of us working in this space now is this ability to tune the spectrum of light, as well. And so in this case I have three different spectral

power distribution graphs shown. You can see the blue line on your screen is marked 6,500 K. So that's 6,500 Kelvin.

And this is a lighting system we studied in one of the schools where you could tune it so that you had a very cool light. And you can see the peak of that graph is in those shorter wavelengths, the bluer wavelengths, if you will. And then as you move out through the red, orange, and yellow, it sort of drops down relative to the other ones. So that light appears to be bluish. You see a picture to that effect on the bottom right of the screen.

And there's a gray line in the middle that shows a 4,300 Kelvin, less blue, relatively more orange, red. And then the 2,700 Kelvin, that's basically the color temperature or the color appearance of an incandescent lamp. We're all familiar with that very nice warm incandescent light. And so this LED system you can tune all the way down to 2,700 Kelvin, where there's less – relatively less – of that short wavelength blue light, more of the red and orange.

And so we have looked at a couple different schools where they put these in. And the question might be, "Why are people doing this? It's cool that you can do that. It definitely costs more to do that." Right? You can buy LED systems that are just 3,500 Kelvin or just 4,000 Kelvin, or just 3,000, whatever color temperature you want, what I call static color. You have to pay more in order to get this dynamic where you can vary the spectrum.

So why are people doing that? Well, we'll go to the next slides, and the main reason that this has become a big deal right now is the new science that Tracy hinted at on how light affects other parts of our brain system other than just vision. And so I put the word circadian on here. You're all, I assume familiar with the idea of circadian rhythms.

And what we've learned in the last 20 years is that those photo receptors in your eye that I said mostly respond to that green-yellow light, that they're the ones that drive our visual system. But what we just learned within the last 20 years is the discovery of another type of photo receptor in your eye that we never realized was there before. And this other photo receptor actually doesn't contribute directly to vision. It contributes to other bodily functions, other biological functions.

One of those is the circadian rhythms that your body goes through. And part of that is the production of the hormone melatonin. You produce melatonin in the dark and you stop producing melatonin in

the light. And it turns out that the shorter blue wavelengths are the ones that are most powerful for affecting your circadian rhythms. And so to stop melatonin production in the morning, if you get outdoors you're exposed to a lot of bluish light. That stops it. To produce a lot of melatonin at night you don't want to be exposed to blue light. You want to be in the darkness. That's why the controversy about sort of looking at blue computer screens can keep you awake.

So that's one reason – the main reason – I'd say that a lot of people started looking at this ability to tune the spectrum is the new science on circadian rhythm and some of these other effects. That may not be that relevant in schools. Where it's mostly relevant is applications where people have to sleep while other people have to work. And so we think about hospitals, and senior care centers, and other places where there's shift workers, and control rooms, or prisons, or even dormitories. That that's where circadian effects are probably the most important. Maybe a little less so in schools.

So then what about in schools? Well, in the next slide I brought in a couple other things that have come up about why tunable LED systems might work in schools. The first one says alertness on the bottom right. Those photo receptors I mentioned that are mostly sensitive to the blue wavelengths, we've learned they're not only connected to the parts of the brain that control circadian rhythms, but they also are connected to parts of the brain that can immediately affect your level of alertness. Sort of that same idea that when melatonin is suppressed, you're more alert.

And so there is some studies that have been done in schools indicating that there may be an effect on student concentration levels, for example, if we can expose to some of this shorter wavelength light, the kind of cooler light.

Beyond that, we've just seen that giving the teacher more control of a classroom and the opportunity to sort of give cues to the students to make a change in the room and through lighting can be cues to the behaviors that the teacher desires in the room. So I just put the words "behavioral cues."

Now, on the next slide I just bring in a bunch of other reasons. We're seeing lots of different applications of tunable lighting, lots of different reasons people do it. I won't go through all these. If you're not familiar with the concept of biophilic design, I'll mention that one. Biophilic means trying to mimic the outdoor condition indoors.

Certainly the spectrum of light outdoor changes throughout the day. You think of a sunset or a sunrise and the colors in the sky. This idea of just giving more control in the environment, letting people pick their preferences, creating different atmospheres, those kind of things are all important elements of this. Next slide, please.

What I want to do with the rest of our time is give you the highlights of a couple of pilot studies we looked at. When I say "pilot studies" these are schools that picked, in each case, three different classrooms where they wanted to test out this LED tunable lighting. You can see these two reports. This is actually the cover from the reports without the logos on them. But those, one was September, 2017. One was just September of this year. One school in the Carrollton-Farmers Branch school, CSB, that's outside of Dallas; and the other one in Folsom, the Folsom Cordova school district.

When we get involved in these projects, we are partnering with the schools, certainly. We often have a utility partner, SMUD in Sacramento. Folsom schools are in their service territory. In Carrollton we didn't have a utility partner, but the engineering design firm that worked on the project worked closely with us. And then the manufacturer is often also involved because they're trying to learn about their systems and how people are using those systems. And so one of these was an Acuity brand system in Carrollton, and then a Finelite lighting system in Folsom.

I'm just going to get us not a lot of depth from these reports. There's a lot of technical detail we can get into. But I want to give you sort of the high-level what kind of controls did they use? What did we find in these studies? This is a teaser, hopefully, to make you want to dive in and get a little bit more.

And so if we can go onto the next slide, we'll look at the first project that we did, which is the one that was published just over a year ago now in the Carrollton-Farmers Branch schools. So this was the Acuity brand system. And again, I think you will realize DOE is here just to sort of study the technologies, not – no endorsement or anything, no funding of this came from the manufacturer. They just were involved as a partner in helping to set up the study.

This is the control system that's used in the Carrollton-Farmers Branch classrooms. You can see this is the teacher's control. And so what I did with outside of the box, outside of the switch plate.

I'll show you what the controllers do. And so in this system, interestingly, the system lets the teacher pick one of four specific color temperatures. So the teacher doesn't have independent control and get whatever color they want. Sometimes that can be a little too confusing. Instead, it's just a push-button system on the left side of the screen that does four buttons.

And I'm an engineer. And so my first thought was, "Well, just label the buttons 4,200, 3,000, 3,500, 5,000." Right? And then the school folks, of course, say, "I don't think our teachers actually understand what that is. And if we have a substitute teacher show up, they certainly aren't going to understand what those are." So that's a fair point. We can't let the engineers rule the world.

So instead of those labels, the manufacturer chose the labels you see on the screen. There's one button that just says "general." And when the teacher pushes "general" all the fixtures in the room go to 4,200 Kelvin. If the teacher goes to "reading" that goes down to the warmest setting, 3,000 Kelvin. And testing, 3,500.

And notice the 5,000 Kelvin. That's the coolest one, the bluest one. Right? And that button says "energy." That sort of relates back to what I just shared, that those shorter wavelengths seem to increase alertness. Those are the things that are tied into the circadian rhythms and all the other things we talked about. And so those were the labels that the manufacturer chose.

Now again, most places will allow you to customize. You can sort of get whatever words you want on the label. But that's what was used in this project.

The right hand side of the switch plate. shows a scene controller. Scene controllers don't change the color. What they do is change the switching scheme or the dimming scheme for the fixtures in the room. In this case, the scenes were just left as numbered one, two, three, and four.

Part of that's because these systems allow you some flexibility that if you change your mind down the road about what you want those scenes to do, that's just in the software. You don't need to change any wiring. You don't need to get up in the ceiling. You just change the program. And you can change what those scenes allow you to do.

And so in this particular case, in these three classrooms, scene one turned all the lights on at full output, 100 percent. Scene two is if

the teacher was now going to give an audiovisual presentation it shut off the fixtures that were right in front of the screen. And you can see in the picture shown here there's kind of three fixtures going across the front of the room. Those fixtures would go off, and the rest of the room would dim down to 40 percent.

Now it's important that the rest of the room dims, but doesn't go off. Right? So the students still have plenty of light. They can be taking notes. But you don't have a lot of light getting on the screen. As opposed to the typical fluorescent classroom, where oftentimes it's all on, or all off, or maybe you can get half on and half off with a couple switches. But this ability to turn the front of the room off and dim the rest of the room can be a nice thing for the teacher.

Scene three, they decided they wanted a scene where now what we call it the presentation mode. So now students are giving short presentations, or even if it's the teacher wants to bring more focus to the front of the room, scene three brought the front of the room up to full and the rest of the room dimmed down a little bit. And then scene four was just kind of an overall dim level.

The other thing you see on that part of the controller is just an on/off. Right? That can just be used anywhere. So you just turn off, and everything shuts off. If you turn on, it comes back on to whatever state it was in before.

This controller was always at the front of the room. It could be at the front of the room where the teacher can access it, and then you can have a separate on/off control near the door. In this case as these were retrofit as a pilot, they didn't put the controller up near the front. That would have required too much wiring. So they were near the door of the room.

And then you also, if you look at the bottom right corner of the control panel, you see just a little up and down arrow. And that way the teacher could always dim, raise or lower, the intensity level just by pushing those buttons. So say they hit A/V mode and they thought, "Oh. That's a little too dim." They could just hit that up arrow a few times to change the lights. So that's the way these tunable systems work. Every system has sort of a different controller to it.

But if we look at the next slide on what that actually does in terms of the spectrum of the light, just to show you this again so you're getting more and more familiar with these things if you haven't seen these before. These are the spectral power distributions of

each of those four settings. I added the labels in just so you can see how as you go from 5,000 Kelvin down to 3,000 Kelvin, again you're reducing the shorter wavelength, the blue light, and increasing the longer wavelengths, the red and orange light.

So the 3,000 Kelvin is the warmest setting, has the most sort of red and orange wavelengths. And the 5,000 Kelvin is the coolest setting. And you have these four distinct settings, so you can't change continuously that you get each of those four settings.

If you want to know what that looks like, the next slide we got some photographs taken to show the room in each of those conditions. And hopefully you've had some experience with this. The photos definitely sort of emphasize the differences when you put them all beside each other.

The reality is that when you're in this classroom in any of these four settings it just looks like white light. If you walked out of the room down the hallway and I changed a setting and then you came back, it wouldn't be that obvious to you that anything had changed. If I went from 3,000 to 5,000 and you were just out of the room for a short time, you might come back and say, "Oh. Yeah. This is cooler." But it's not quite the dramatic thing we can see when we put them side-by-side like this.

But the side-by-side just lets you see that you do have now this range of control that allows the teacher to sort of create the environment he or she wants. If they go to the A/V mode and they were – let's say there were in the energy button to 5,000 Kelvin, and then they switched to A/V and they felt like, "Oh, this dim light when it's so cold, so cool, doesn't seem like the students really like that." They can quickly go back and push the reading button, for example, or the testing button, and make it a warmer tone, even while still in the A/V mode.

So with this control system that control of the scenes only controls switching and dimming, and the control of the left hand buttons on the controller changes the color. Those two things kind of happen independently.

I'm going to go over some results of these studies after we talk about both of them. But I did want to show you now the Folsom project. So if we can go to the next slide – I showed you this slide before, just to illustrate what the fluorescent system was.

And so in this case, in the Carrollton-Farmers Branch, the Texas school I just talked about, that was a one-for-one luminaire replacement. So they had those rooms with fluorescent fixtures in in the exact same configuration. There were sort of 9, or 12, or 15 fixtures in each room, depending on the size of the room. And in that case they just came in and took out the fluorescent fixture, popped in the LED fixture, didn't rewire the room at all, added the new controller.

With Folsom Cordova, they realized that this fluorescent system that they had, although it was laid out this way for a reason, to get a lot of light on the walls, the light levels were really higher than they needed to be. The distribution of light wasn't really what they wanted it to be. And so in this case they redesigned the lighting system for the classrooms to go with many fewer fixtures and put in the LED fixtures. So this was sort of the base case condition, and then they went with a more uniform pattern in the normal condition.

But I did want to talk about the controls here, because the controls are very different. So if we go to the next slide – thank you. So and again, different manufacturer with classroom system will have tried some different controls. And one of these we're really interested in, and that's why we want to find out more about the experiences of those of you that are in the webinar today, because we think there's a lot of interesting research questions about what type of controller is going to be the best for teachers, and what will support the school learning environment the best.

This is the control panel that was used in the Folsom Cordova school classrooms. Again, three different classrooms where they piloted this system. In this controller, you can see the left hand column is basically the scene controls like we saw in the prior control system. But in this case, the scenes both set the switching and intensity and they also set the color.

So each of the scenes is sort of preprogrammed to do that. And so there's a general scene that, again, brings all the lights on at sort of a mid-range color at a certain intensity. And then an interesting thing in this project is when they were first installing these and we were working with the folks from the utility, from SMUD, who also very interested in energy efficiency, because the older classrooms were well above recommended light levels.

With the LED system – if the LED system was run to 100 percent, it also would provide more than the recommend light. And so they

worked with each teacher in the classroom to find out what light level did they want for their classroom? And then they programmed that for the general button. And we actually found that in all three cases that general button was programmed to be somewhere between 50 and 55 percent output. So the teachers didn't even want it running at the full output, so more savings could be kind of harvested through that.

A/V mode, similar to what we talked about before, sort of shuts off the lights near the front of the room, dims the rest of the room. In this case, they wanted a screen setting. That means that in some schools today there's times when all the students are working on a tablet device, and they all have screens in front of them, and the light – sometimes too much light can be a problem in that setting. So the screen setting sort of dims the light down for that.

And then you can see an energize and a calm setting on the left, where energize and just even the color on the controller, the manufacturer is trying to indicate to people this is going to be bright and blue. And for calm, we're going to make it more sort of a warmer dimmer setting like the sunset. And so the teachers could use those buttons. The sensor override has to do with occupancy sensors. We won't go into that here.

And so on the left side of this, if the teacher wanted to, they could do everything they wanted just from the left side. They have a power button at the top. But then the three slides on the right side – if we go to the next slide, thank you – I call them slide controllers. They're really a touch slide, so there's not a mechanical slide like many dimmers have. In this case it's just sort of a touch screen.

And so if you put your finger on down lights up at the top and swipe down, you dim all the lighting in the room. So the down lights really mean the troffers that are in the room. And then there is a separate whiteboard light in these classrooms. And so the teacher now can raise or lower the intensity from the room lighting. They can raise or lower the intensity for the separate whiteboard light. And then in this system they can also change the color continuously. So you didn't have to pick from four buttons, like in the previous one. In this one you can change the color.

Now, again, there is discussion about is that just too much information, right? Is the teacher getting overwhelmed now of trying to know what they want? Maybe just having to make choices on buttons is better. I think those are really interesting questions. And that's why we do these pilot studies.

So that's the control system that was used in the Folsom Cordova in the three classrooms there. Just to show you sort of what that ends up looking like, I don't have pictures of each of the different colors, but if we go to the next slide, now you remember from the first project the total range you could go was from 3,000 Kelvin to 5,000 Kelvin. This system – and these are one of the variables in color tunable systems, that if you get into this you have to think about and work with your design team.

This particular system gives a bigger dynamic range. And so you can go from 6,500 K – which is cooler than the 5,000 K of the other system – all the way down to 2,700 K, warmer than the 3,000 K. There's, like I say, in applications where you have people trying to sleep, like a hospital, you might want a broader dynamic range. In a classroom maybe you want to limit it more.

So it's really up to what you and your design team think would be appropriate. But in this case you could change continuously. I just picked those three numbers, but actually that spectrum between 2,700 and 6,500 you can kind of tune it to anything in between those two.

Next slide, please. We'll show you a little bit about the energy use, since we are the Department of Energy. What we did here was worked out some hypothetical scenarios of how the teachers might use the room based on some data we had from the teachers. There is monitoring equipment set up in the school now. We haven't analyzed all those data yet. But here just to give you kind of a hypothetical example, what this is showing is a typical day in the life of the school under the fluorescent system.

Now in their fluorescent system they did have two switches, so you could switch down to half. Those two switches actually switched every other fixture. If you remember that layout in the rooms in the Folsom. There were a lot of fixtures. So it didn't do anything in terms of A/V mode or anything. It just switched off half the fixtures. Right?

And so the gray boxes here are just showing whether the fluorescent system was running at 100 percent or 50 percent. It was off at lunch time. Good job. And then it comes back on in the evening for the cleaning crew. And then the orange line is showing you the energy consumed during that time period. Right? So the fluorescent system comes up when they're on full. Obviously, it comes up less when it's on at half.

If we then compare that to what a day in the life with the LED system looked like on the next slide, I mentioned to you that the teachers themselves had decided – whoops. There you go. Thank you. The teachers themselves had decided that they wanted a little bit more than 50 percent. Now it's not that it was 50 percent of the foot candles of the previous system. It's just that it was 50 percent of the LED output. And in the report we go through all the details of what actual light levels they end up with.

And so and then if you switch to A/V mode, that dims those lights down and turns some off. If you go to energize, it bumps them up a little bit and goes to blue. If you go to the screen mode, it dims them down. Right after lunch the teacher liked to use the calm button because the kids are kind of all wound up when they come back from lunch, and so a short time to have the lights pretty dim and warm and just ask the students to sit quietly.

And you can see overall if you just look at the right-hand axis you're down to less than a quarter of the energy that was used by going to the LED system. That's a combination of a couple things. One is the wattage of the fixtures is much lower. Two is they did reduce the light level some. That always helps with the energy story. But three is this idea that they could be dimming and using these different scene settings to help with the energy use.

One important point I'll not here, some of you might notice that the blue line actually is going up before the lights come on in the morning. You might say, "What's up with that?" That was a surprise to the SMUD folks. But many of you, if you've had any experience with some types of digital controls of lighting there can be some – the quote-unquote phantom load.

Digital control devices often have to remain powered on even when the light fixture is off so that they can take the next signal that comes in digitally. And so in this case there is some phantom load and you are using some energy, even when things are off. And depending on your application, they still saved a ton of energy, but could save even more if we could figure out how to not have the phantom load there. Next slide, please.

In this slide I just wanted to mention one of the things that we're really interested in and we're happy to partner with some of you, if we can, on future studies. This school was doing surveys of the teachers and students and also some parents to get some feedback from them on the lighting. The data we've been looking at the data.

The best way to do it is to also be surveying people that didn't have the new lighting. In this case, that wasn't done. And so it's hard to derive any strong conclusions.

But I just mentioned this to sort of let everyone see how these things play out, how these projects play out, and for those of you that might be doing some work with this, if you have an interesting project, we'd love to hear about that.

So before we go on, I think we have another poll that I wanted to close with, and then we'll do a quick wrap-up and move onto some Q and A. So with this next poll, the earlier question asked you about your experience with LED lighting, and we're just curious to know how many of you have actually tried out any of the tunable lighting. So please respond to this poll with any experiences you have with tunable LED lighting.

All right. If we can see those results whenever we have enough. All right. That was sort of what I thought. Most of you have not really done this. Some have done pilots. Those of you that say you have at least one full school, if you think there's some interesting research possibilities there or interesting things to look at, we would welcome the contact. My e-mail is shown at the end of the presentation.

So let me just wrap up with giving you some of the outcomes on the next slide. What we found in these two projects – and I'll talk about both of them together here – was that just based on converting from fluorescent to LED, the power reduction and sometimes a reduction in light level, between the two schools they were looking at 45 to 60 percent energy savings. And that was not even thinking about the dimming. Right? That's just saying the fixtures are lower power, less watts. And then when you factored in dimming, as you saw in that other slide, those savings went up to over 70 percent.

In addition to the energy savings, on the next slide, one of the things that we are sort of interested in when there's a new technology is does the color stay consistent when you put in a bunch of fixtures? And when you start to dim, does the color shift? And we were quite pleased in both of these projects that we found the color consistency between the fixtures and over the dimming range was really, really good.

And we've found other – we've done work on this in health care and in senior care and other types of applications and we've seen

the same thing, that the manufacturers really seem to have found a way to keep that color consistent.

I mentioned this idea of behavioral cues. And when we went into this, we didn't realize how powerful this could be. But we found that in this case it's just two schools with three classrooms each, but as the teachers got familiar with the system, they provided feedback to us that said, "You know, we feel like this really increases the student engagement. And when I can senses things kind of starting to get a little out of hand in the room, if I change one of the scene settings, if I change the color of light, that gets the students' attention right away."

And also sometimes the students as they learn about the system, they start to say, "Oh, why don't we go to this mode for a little while?" And the students were kind of interested in how it changed the environment. And so the teachers certainly really felt like it was improving the learning environment.

I should mention – and we don't want to go into much depth on this. There's not a lot of depth that we studied. But one of the reasons Folsom did this is they were interested in some of the special needs classrooms. And so two of the three classrooms we looked at at Folsom were classrooms with students that are on the autism spectrum. And those teachers really felt like this idea of behavioral cues could be a powerful thing.

And then the other things I did, just one of the anecdotes, if we go to the next slide. And as a scientist, I don't want to put too much value in anecdotes. But it was sort of a powerful personal story that we heard from one of the teachers who told us, shared with us, that he was about ready to retire because he had ended up missing a half dozen days or so every school year over the last few years because of migraine headaches.

And he was fairly certain that the fluorescent lighting system was contributing to his sort of culpability to migraines, and found that once he had lighting where he could do a lot more control himself, and dim it if he needed, and avoid some of the issues with fluorescent. He basically told us that, "I decided I'm going to keep going. I've got a few more years. And I like this room a lot with this different lighting." And so he sort of said that getting away from the fluorescent lighting was what kept him from retiring, which we thought was a pretty cool story.

So overall final summary on the next slide. We think there's some great energy and economic benefits you can get from LED systems, and dimming and scene control, even without the color part, right, is the first two bullets here. Dimming and scene control can really offer some deep savings in schools.

Now I have here tuning the spectrum can offer further benefit. But I do want to emphasize that there is no further energy by changing the spectrum. Right? You get all your energy savings from just the efficacy of the LEDs and the power reduction and the dimming. But changing from warm to cool light doesn't change the power, generally. It doesn't change the wattage.

And so now how do you justify paying more to get that tunable spectrum? That's when we talk about some of these non-energy benefits, often abbreviated NEB. This idea of giving teachers more control of the classroom, providing visual cues for students. And some people are making strong arguments for the alertness and student concentration.

That science, I think, is still emerging. There's still stuff we don't know about that. But one thing tunable lighting does is it sort of allows you to be ready to adapt, right? If we start to learn that, yeah, you really do want more short wavelength light first thing in the day, or maybe right after lunch, but having these kind of systems sort of helps you to future proof for that.

A list of additional resources you can access later that we have mentioned in this presentation. And with that, I know we've had some questions coming in. We're at an hour. Let's move onto some Q and A. So I'll turn it back over. I think Crystal is going to help to manage the question and answer.

Crystal McDonald: Yes. Thank you, Bob. Thank you, Tracy. We appreciated the presentations. They were very informative. And yes, we do have several questions that have come in. And what we will do – because we are over time at this point. But what we'll do is just respond to the first one, which I think most people are interested in.

And the question is how do I access the K12 toolkit and when will it be available? The K12 toolkits will be available on the Better Buildings Solution Center. We will send notice when the toolkit goes live. In the meantime, please take advantage of the resources that are in these presentations. And we'll be sharing the presentation with you in a follow-up message, as well.

And also for those who have sent questions in during the course of the presentation, we will respond to you directly by e-mail so you will get those responses very quickly.

So we hope you'll plan to attend the next Better Buildings webinar on Tuesday, December 4th, from 3:00 to 4:00 PM Eastern. And that one is around technology research team showcase. We'll hear from our labs and the latest available information on high-performance technologies. And so with that I'd like to thank our panelists once again for taking their time with us today. And we ask you to feel free to contact our presenters directly with additional questions or if we weren't able to get to your question during the Q and A period.

If you'd like to learn more about the Better Buildings Challenge or Alliance, please check out our website or feel free to contact me directly at the e-mail shown. I encourage you to follow the Better Buildings Initiative on Twitter for all of the latest. You will receive an e-mail notice when the archive of this session is available online. And once again, we thank you for your time today and enjoy the rest the of your day.

[End of Audio]

Q&A:

- **Question:**
  If I did a lighting efficiency upgrade to high performance T-8s 5-7 years ago, will it be hard to justify an LED upgrade now?
- **Answer:**
  No! It is definitely worth looking into. Depending on your local utility rates (and possible utility rebates for energy efficient lighting products), it could be completely cost-justifiable. Options for upgrading linear fluorescent lamps have become quite robust in the past several years, and the cost for many options is incredibly reasonable. Additionally, with new ballasts in your luminaires, you might have the option of using “Type A” TLEDs, which operate off of the existing ballast and remain the easiest installation option. Another great resource that you might want to look into is DOE’s Interior Lighting Campaign (ILC), which would provide limited technical assistance for your organization during the decision-making process, and possibly provide recognition of your successfully implemented project if you submit your data after the project is complete. Feel free to email me directly (tracy.beeson@pnnl.gov) as I also provide participant support on that program as well.

- **Question:**
  Do the photoreceptors that affect circadian rhythms have a name?
- **Answer:**
  The recently discovered photoreceptors are the intrinsically photosensitive retinal ganglion cells, abbreviated as the ipRGCs. In general, the retinal ganglion cells form a layer of neurons in the human retina that receives input from the rod and cone photoreceptors (through an intermediary layer of cells such as the bipolar, amacrine, and horizontal cells) and then carry that signal through pathways that lead to the visual cortex in the back of the brain. The new science proved that a small percentage of the retinal ganglion cells (less than 5% of them) are also photosensitive themselves – the ipRGCs. Unlike the other ganglion cells, the ipRGCs connect to brain regions other than the visual cortex. The science regarding all the connections in the brain is still emerging, but we know that some of the ipRGCs connect to brain regions that affect circadian rhythms and melatonin production, for example.

- **Question:**
  Is your case study for energy use based on T-12s or T-8s?
- **Answer:**
  For the two classroom pilot studies presented in the webinar, the baseline fluorescent lighting system used T8 lamps.

- **Question:**
  Is there a report or database that details how many lamps /linear LEDs/etc. failed in the first three years in some specific installations (and # installed) -- for example, for the case studies -- and which specific brand/model those were, to help guide decision making?
- **Answer:**
  The two classroom studies presented in the webinar were new installations, so long-term data are not available. However, DOE published a GATEWAY report in February of 2017 that evaluated long-term performance of LED lighting installations in four locations. You can find that report and others at: https://www.energy.gov/eere/ssl/gateway-indoor-projects

- **Question:**
  What are the studies that show the behavior and engagement improvements with lighting upgrades?
- **Answer:**
  Although detailed data of this type from scientific studies is still needed, the pilot studies presented in the webinar have some discussion of these effects. The current reports are at the DOE GATEWAY indoor projects web site. Check this site regularly for future updates, which will also be linked into the new Better Buildings K-12 Toolkit: https://www.energy.gov/eere/ssl/gateway-indoor-projects

- **Question:**
  How would these different scenes and settings apply to daylighting and occupancy sensors?
- **Answer:**
  In general, daylight and occupancy sensors can operate as an independent layer of control from the scene controllers. Daylight sensors are usually configured to control a set of luminaires within a defined daylight zone, and can be configured such that those luminaires dim if the chosen scene setting results in a light level that is above the specific daylight goal. Occupancy sensors in classrooms usually act to switch off all the classroom luminaires after a period of inactivity; with most scene control systems a subsequent “on” command (either from a manual button push or automatic motion sensing) will either return the system to the scene that existed when it switched off, or to some pre-defined default condition.