Axel Pearson: Hi, everyone. If you're just joining there's a trivia question on the screen. Go ahead and answer that question. There should be a box that pops up that allows you to answer that. We're gonna give it just a minute or so for other folks to roll in. I see the numbers steadily increasing. So that's great. Again, if you've just joined, we're allowing a little time. Feel free to answer the trivia question that you see on your screen. We'll get started about a minute after.

Okay. We're about one minute after. We'll go ahead and get started. I'll give you a last chance to answer that trivia question. What crop is most commonly grown using Controlled Environment Agriculture (CEA)? Okay. Jasmine, let's move on to the title slide. All right. Well, hi, everyone. Welcome to this Better Buildings webinar titled Not Your Garden Variety Grow Space: Integrated Lighting in Greenhouses. My name is Axel Pearson. I'm coming to you live from Salt Lake City, Utah. I'll be your host today and we have another great program for you today.

We're switching it up a little bit this time to talk about a different lighting application than we typically cover. We'll hear from two greenhouse experts who I'm honored to introduce in a couple slides and they'll tell us about their integrated grow spaces. I will also take a little time to tell you about the upcoming year of the integrated lighting campaign and some new recognition categories that we have there. So thank you so much for joining today, taking time out of your busy day to listen in and participate. Really appreciate it. I hope it's valuable for you.

Next slide. Let's take a look at that trivia question. If you joined in time to answer the trivia question the correct answer is – one more click – (C) salad greens. This comes from a survey of 366 growers. Fifty-eight percent of those growers listed salad greens as a crop and a close second, herbs came in at 49 percent and no, not that type of herb, followed by vine fruits and berries. Let's see how many people got it right. Jasmine, can you please share those results? Oh, that was too easy. Oh, but did trick you a little bit with the vine fruits though, but most people did select salad greens. So nice job. Awesome. Congrats to those of you that got it correct.

Let's move on. First, some quick logistics before we get started. Slides and the recording will be posted shortly after the webinar on the Better Building Solution Center. I'll also send an e-mail out to all the folks that registered when it's available. Next, feel free to enter your questions into the Q and A pane of Zoom and we'll take a look at the end of the webinar, answer them as best we can or as time allows. If we can't answer them or don't get to all of them, I

will be sure to follow-up with you via e-mail. Finally, you can always reach out to us at IntergratedLighting@pnnl.gov with questions and comments. So don't hesitate to shoot an e-mail over there.

Next slide. Here's the agenda for today's webinar. First, I'd like to introduce you to the speakers you'll hear from today. Then briefly tell you a little bit about our recent work and upcoming events. Again, I'll take just a little bit of time to tell you what we've got in store for the 2023 Integrated Lighting Campaign. Then we will get into the meat, or should I say salad greens, of the webinar. That's my last one. Don't worry. Our guest speakers are both recognized in this year's Integrated Lighting Campaign under the category of integrated lighting and horticultural controls. This means that their grow spaces integrate with lighting and HVAC and irrigation and other critical greenhouse systems. So I'll introduce them formally on the next slide. I'm super excited to hear from them.

So that's what we've got ahead of us for the next hour or so. Again, feel free to send questions as they come up into the Zoom Q and A pane. Next slide, please. Here are today's speakers. I'm there on the left. Again, my name is Axel Pearson. I'm a project manager here at the Pacific Northwest National Lab. I lead the Integrated Lighting Campaign and the lighting systems technology research team. So that means I get to put events on this one and put events on like this one and interact with you all.

In the middle is Hannah Bouline, the director of impact and sustainability at Vertical Harvest Farms. Hannah is a sustainability advocate and an expert grower. She works with the vertical harvest team to devise, deliver, and drive on vertical harvest environmental and social impact targets. With an MBA in sustainability and years of working in the flagship Jackson Hole greenhouse, Hannah is responsible for working collaboratively across all departments and within all farms to improve sustainability in order to provide a positive impact on employees, on the communities where the farms are located, and the planet alike.

Our second guest speaker is Derek Allen, the greenhouse facilities director at the University of Vermont. Derek is a horticulturist with over 17 years combined experience in pant cultivation, research, and production. He has worked in facilities across the controlled environment spectrum and has managed facilities at multiple academic institutions including University of Washington, the University of Virginia, and currently the University of Vermont. Derek has a master's degree in environmental horticulture and

applies his knowledge and experiences towards enhancing integrated pest management best practices, improving energy efficiency, and reducing horticultural waste in controlled environments. Thank you so much for being here Derek and Hannah. Again, I'm really excited and congratulations again on your 2022 ILC recognition.

Next slide, please. Before we get started, there's a few things I'd like to mention just quickly from DOE and our partners. If you attended our last meeting on germicidal ultraviolet light or GUV, you might remember that we're looking for host sites to evaluate this technology. If you have or are interested in installing GUV in your building, let us know. We'd love to work with you. Next, as you might guess, a third year of the Integrated Lighting Campaign is opening at the new year. More to come on that in a couple slides.

There's also a deadline coming up for the L-Prize, which if you're not familiar is a challenge that offers cash rewards for innovations to rapidly improve lighting performance. If you're interested in participating you must submit your intent to submit by January 13. In industry news, the Design Lights Consortium or DLC has released version three of their horticultural technical requirements. So if you're looking for grow lights that meet the most up-to-date energy and quality standards of performance and you're looking for utility rebates, check out the DLC QPL.

Finally, some events that you should be aware of if you're not already, I have two webinars coming up in February on the ILC, both opportunities for supporters and participants. So I'll cover a little bit of what I'm gonna say then today, but if you want more information join those two. There's also the NALMCO spring seminar that will be held in March. They have some good trainings and content at that event. So I encourage you to attend that if you're interested. Then also there's the Better Buildings Better Plant Summit April 11 to the 13th. When you get the slides you can click on all of those for more information.

Moving on to what brings us together today. This webinar is a production of the Lighting Systems Technology Research Team. We aim to reduce lighting energy used by sharing insights and experiences related to emerging lighting and control systems and documenting solutions. We wanna share our work with you and also get your input on how we can help you save energy and improve your buildings through lighting. If you've attended these webinars this year we've been asking all of you to complete polls during webinars, answer surveys via e-mail, and you've given us

really valuable feedback that really truly helps us drive our work and allows us to provide you with resources to help save energy in buildings. So I hope to keep this momentum going in 2023 and I hope that you'll keep joining our meetings in providing us with your valuable input. If there's a topic you're interested in that you want the lighting experts here at PNNL to cover, please let us know.

Next slide. On to the Integrated Lighting Campaign. I hope you're all familiar with the Integrated Lighting Campaign, but if not, just like the name sounds, the ILC recognizes innovative lighting projects that push the envelope in terms of integration, energy savings, novel capabilities, and non-energy benefits. When recognized participants get announced at the IES annual conference. We develop case studies and info graphics and videos. DOE will send out promotions as well. And they have – participants have an opportunity to present on webinars just like our guest speakers today. So if you know of a lighting project that would be a good fit for the campaign, please let me know. I'd be happy to work with you for submission next year.

Next slide. As we gear up for the 2023 campaign year we added some new categories that I'm excited to present to you. What we're showing currently on this slide is the current six recognition categories. These were active this year. I don't wanna spend too much time on them today since they've been a part of the program. So I'll just briefly mention them. Starting on the left there there's the advanced use of censors and controls for lighting. Then we have three separate categories for integrated systems, again, meaning that the lighting communicates with these various systems: Plug loads, HVAC and other systems, could be security, some other IOT application, any integration there.

Then of course there is the integrated lighting and horticultural controls, which is the focus of our guest speakers today. So I'm gonna let them go into detail on that one. Then the last one on the far right is innovative maintenance operation and financing service models. So those are the existing participating categories. They're still relevant for 2023 in addition to the four new categories for 2023 on the next slide. Starting on the left, our first new category is specifically focused on small buildings, which we define as buildings smaller than 50,000 square feet in size. So this category really acknowledges that lighting controls are not one size fits all. Sometimes it doesn't make sense to have a super complex network lighting control system especially in smaller buildings that have a

smaller amount of lumineers or buildings that don't have a building automation system or a dedicated facility manager.

So we're looking for novel room control approaches here that work for the space and the occupants. Next we have a category for germicidal ultraviolet or GUV systems for energy savings and improved indoor air quality. This is obviously a hot topic right now. It has been for the last couple of years. It's a promising technology for safety in buildings. We wanna recognize projects that have successfully deployed energy efficient GUV systems in buildings to reduce the spread of airborne pathogens and improve indoor air quality.

Our third new category is sustainability and lighting, also a popular topic and we wanna highlight projects that have successfully minimalized their environmental footprint in impacts across the project lifestyle. This could be using products that are serviceable, those that are made of recycled materials or other sustainable materials, approaches that extend product lifetime and support maintenance or improved end of life outcomes like reuse, remanufacturing, recycling, proper disposal of e-waste.

Finally, the last new category is energy justice, diversity, equity, and inclusion in advanced lighting. So this is a participant category. We also have a supporter category that exists this year. I'll cover that briefly next time, but this is for the participants and that's new this year. It seeks to recognize advanced projects which successfully incorporate these JDEI practices. This can include siding, installation, contracting or procurement. An example is a lighting retrofit in a building or site that offers benefits to local disadvantaged communities like offering education on the energy savings approaches or a plan for donating or sharing costs in energy benefits with the community.

Each of these new categories has more examples on our website. You can feel free to let me know if you have questions, you wanna talk through these a little bit more. There's also a recorded webinar that I did last week. You can watch that for a little more detail and those two webinars coming up in February I'll talk about these a bit more. So I hope I peaked your interest there.

Next slide, please. So again, I'm gonna cover these very briefly. We have recognition categories for supporters of the campaign. These are again, existing categories, but they're slightly revised. We tried to simplify them a little bit. So supporters can be recognized for encouraging the use of advanced lighting controls

and technologies, which we call exemplary supporters and those that support energy justice, diversity, equity, and inclusion can be recognized as the energy justice, diversity, equity, inclusion champion. So we had both of those categories were recognized last year. I hope to get more good projects this year.

Let's move on to today's technical topic. Controlled environment agriculture or CEA. You might remember this definition from the trivia question, but CEA is a method of growing plants while controlling aspects of the environmental conditions including light, temperature, humidity, water, and nutrients, all the things that influence plant growth. So there's a variety of ways to control the growing environment that range from little control to all full control. So there's a spectrum here. Left side of the screen, very little control, all the way to the right of fully control.

So on the left side of the spectrum there are grow tunnels or hoop houses that simply provide some type of structure over open plots of land. Again, they are typically open to the air, but do provide some type of control over temperature, light, and moisture. In the center of that control spectrum we have greenhouses. These are fully enclosed spaces of transparent material like plastic or glass that allows a lot of natural light, but also can include supplemental light in the form of lumineers. They're climate controlled and they must provide water and nutrients to the plant because again, they are these fully enclosed spaces.

On the far right of the control spectrum are indoor grow rooms that require full environmental control including sole-source lighting, HVAC, and humidity control. So because of the range of those application there's really not a one size fits all solution for lighting or HVAC control. So it really takes some finetuning and careful management to achieve ideal growing conditions in each particular space.

Next slide. So why is controlled environment agriculture relevant to the lighting systems technology research team? One, CEA is an energy and resource intensive process, especially the further right that you travel on that control spectrum. To provide that control resource intensive systems are needed like lighting, HVAC humidity, irrigation, and nutrients. However, CEA has the potential to produce very high value crops at maximum productivity and resource efficiency when ideal growing conditions are met. To meet these ideal growing conditions, the facilities horticultural systems like lighting, HVAC, and humidity must be finally tuned and controlled. This is no small feat.

So our guest speakers will go in to what it takes to manage their facilities and grow healthy and productive crops. Finally, integrating these systems can yield synergistic energy savings and just like commercial facilities, the lighting systems and controls can serve as a solid foundation for integration through data collection via censors and providing a network to interface. So that is a key role that lighting and control systems can play. So next slide. Without further ado, I would like to introduce our guest – first guest speaker, Hannah Bouline. Hannah, take it away.

Hannah Bouline: Thanks, Axel. I'm Hannah Bouline. I'm with Vertical Harvest Farms as Axel mentioned. You can go ahead and pop to the next slide, Jasmine. So if you aren't familiar with us, we're a hyperlocal controlled environment agriculture company focused on sustainable farms, food, and futures. We err on that more controlled side of the spectrum that Axel was showing everyone. We have a mission to be local farmers, but also inclusive employers and we're really focused on delivering impact for all of the stakeholders within a community as well as positive returns for our investors.

Next slide. Just a little bit more of a summary of our farm. Our first farm is located in Jackson Hole, Wyoming. We started operating that facility in 2016. Within that farm we have what we call our grow well model where we employee people with physical and intellectual disabilities in our greenhouse. So we were recognized as one of the DEI producers within the ILC campaign. Out of 43 employees in our Jackson Hole farm, 50 percent have a disability.

Within our Jackson farm we produce around 50,000 pounds annually and locally distribute that food across restaurants, grocery stores, and we also donate or build out low cost partnerships with people serving low income and low access community members. So that looks like donations through food rescue groups and working with schools, hospitals, senior living centers, et cetera to make sure that your food is widely accessible across the community. We plan to bring all of these aspects to our next farm, which is currently under construction in Westbrook, Maine and said to open in November of 2023. That's just the start for us as we plan to expand more farms in the coming years.

Next slide. So getting down into the more technical aspects of the farm. Within our farm here in Jackson we have a hybrid farm. It's a combination of those greenhouse spaces vertically stacked into a three story building. And some of our systems are more on the

greenhouse spectrum and some are fully indoor rack systems. Our main farm will be primarily focused on full indoor control and on that furthest end of fully controlling our environment. So integrated control systems are super important for us.

The facility in Jackson that's currently running utilizes a Priva system. There are censors throughout our farm that collect data internally about the climate of the farm as well as externally around the outside climate that we are trying to mitigate against in any number of different ways. Within that system we also set strategies to control our lighting HVAC and irrigation processes. Some of these systems run basically on the thresholds that we set. So they respond to real time data and then they respond to that actively or alert growers to issues in which we need to fix something in the system.

So an example you can see here is in our tomato room, which is on the third floor. You can see there is a glass ceiling here. So we're making use of both natural as well as supplemental light. So we've set thresholds for what the daily light integral needs to be for our tomato plants and on days when it's perfectly sunny, those HPS sites that you can see in the photo will turn off once we've hit the maximum threshold that we need from sunlight whereas the picture on the right, very cloudy, rainy day, but it is day time. The system knows to turn our lights on to make sure that the plants get the required light that they need for their growth.

The interdependence of all of the controlled parameters in the growing environment, lights, CO2, temperature, humidity, nutrients, really requires this type of system. So we have operated this farm with a controlled system from day one. We really need a controlled system to maximize our crop productivity and also to manage these amount of crops that we're trying to manage within our facility.

Next slide. So while we started with an integrated control system across the board for our farms, a big story in our Jackson RND farm has been our lighting improvements. Since we've opened our doors in 2016 in Jackson, lighting efficiency and the grow sector has increased massively. That's in terms of how productive our lighting can make our crops as well as the energy efficiency of the lighting that we have available. So because light is such a large influencer of plant vitality, we have upgraded our lighting multiple times over the last five years within our Jackson Hole facility upgrading new systems as well as trialing different system configurations to see what works best.

Back in 2017 we went through an energy audit with a third party to take a look at a lot of the lights that we had in the building. So starting off with metal halides, some high pressure sodium lights, which were really common in the grow world. We also started off with LED's in certain spaces, especially narrow spectrum LED's. Really this demonstrated the cost savings that we could have for transferring a lot of our lighting to LED's, but also the efficiency gain that we could make in our energy usage. So this was number one case for switching to a lot of LED's was this efficiency case. There are also other arguments for why making a switch to LED's can be really beneficial in a horticultural application.

Next slide. So one of those is light spectrum. So plants harness light as an energy source obviously for photosynthesis, but they use different parts of the spectrum differently in their growth process. So light helps a lot with photosynthesis, but also photomorphogenesis, which informing the structures of the plant, how much are they stretching, how much are they working on developing nutrients. All these different things can be wrapped into different lighting spectrums. Because of this, LED's allow for a more tunable spectrum where we can think about within the best research, what is the best spectrum mixed to balance our crop yields along with our crop quality.

Red light tends to stimulate growth. Blue light tends to focus on quality of the plant growth. So these are the whole range of spectrum. You can see on the chart below the fixed spectrum that you might get from a high pressure sodium light with the yellow line or with a metal halide light. Then you can see even with the narrow band LED that focus on red blue light whereas a lot of research now in this space has shown that light across the spectrum can provide a lot of robust benefits for crop health.

Next slide. Here is a summary of some of those changes that we've seen in our Jackson Hole farm. You can see the transition from 2016-17 when we started out. A lot of our indoor grow racks had narrow spectrum LED's. You see that fully pink light representing a lot of red spectrum and some blue. We also, on the top level of those racks, were still operating with HPS overhead lights. So when we looked towards removing those and looking at maybe an improvement in spectrum we added in lights that had a bit more spectrum, more blue lighting and more white lighting in there as well. So in the middle piece you can see a new configuration that we designed within a separate growing compartment. Those same lights went overhead on the racks that you see in the first photo.

Now today we've built out our newest RND farm within our farm and utilized spectrums of light that really represent more of that rainbow graph that you saw on the previous slide. So with these changes in configuration and lighting spectrum and efficiency, we've been able to improve our energy productivity, which is the energy used per pound of food that we produce by around 72 to 80 percent, depending on the crop. We've also overall improved our canopy productivity which is the number of pounds per growing square foot that we produce by over 200 percent. That's in due in part to crop selection and our design configurations, but also lighting definitely has a major influence on that productivity level.

Next slide. Here you can see the same thing happening not within our rack systems, which is primarily where we grow our microgreen and petite green products, but also with our carousels, which is where we primarily grow lettuce within these facilities. The carousels are a bit of a hybrid working to utilize outdoor light as well as the supplemental LED's. Even here you can see our supplemental LED's on the left with that narrow band spectrum and on the right with more of a full spectrum.

Next slide. Beyond energy efficiency and allowing for a tunable spectrum, our LED changes also help us with lighting intensity. So in 2018 we did a study with the University of Wyoming to add more light censors and DLI censors to our growing spaces in particular those carousels that you just saw which rotate the crop so that they're making use of natural light and also so that they bring the crops to workers as an additional accessibility feature of the farm.

That study showed that a lot of our canopy was underlit and you can see that in the graph of one example carousel to the right, which is one of our most poorly underlit carousel in the building due to its location having a side wall that wasn't glass, things of that nature. So part of that was the narrowband LED's trying to get maximize enough sunlight. Then also these carousels had HPS lights overhead. So the recommendation here to increase light levels on all of our carousels in order to get our DLI up to that ideal range of 12 to 14 for their maximum growth was to add in – to improve our current LED bars as well as adding in additional LED bars, especially along the horizontal sections that come towards the interior of the building.

So this actually – this switch wasn't one for one in terms of energy. We're asking for – we're putting in more lights to appropriately

improve the canopy. So we actually saw an uptick in electricity use from this, but because of the improvements in crop yield we can still see our improvement on our pounds of production per energy units used. It's important to note that when making these changes obviously we looked at the financial component of the payback on them and the anticipated yield gains, but these decisions can't be made independently of the other control parameters in the farm.

So when making changes to lighting you have to think about the positive or negative impacts on the farm climate that might need to be considered in tandem with this. One example is those HPS lights that we were moving from overhead on the lettuce also put off a lot of heat. So switching to LED's could be a positive in terms of the summer climate mitigating that extra heat that might be coming off lights, whereas in the winter climate though we might have wanted that extra heat and now need to rely more heavily on our HVAC systems in order to provide that.

Next slide. So here you can see that transformation with our lettuce carousels started from 2016 through 2018 where we had the HPS lights overhead and you can see where those HPS lights were overhead on top of the rack systems as well. We had the narrow band LED's along the vertical plain of the carousels which you can see in the very background on the picture to the right. So in 2019 we transferred those. We removed those narrow band LED's and went to the full spectrum LED, which you saw on the previous slide.

Then within the last couple of years we've added a couple of different types of LED lighting along the horizontal plain to help improve the crop growth. You can see the difference in the lettuce heads from left to right as well. So this jump was not maybe as massive as our reconfigurations in the rack system side, because like I said, we're using more electricity since the canopy was underlit period and we weren't reaching that appropriate light intensity. But this still resulted in a better energy productivity of around 22 percent are lettuce crops and improved canopy productivity of around 30 percent.

So that's just a bit about our lighting journey here in our facility in Jackson Hole. All of this has gone into the design of our next farm and where we will start off with our lighting intensity spectrum and efficiency in our next farms. All of this is also made possible by that integrated control system, which we need in order to analyze data to make these decisions. In both of these photos you can see a little beehive hovering above the carousels and those are

our climate censors throughout the building feeding that information back and allowing us to manipulate the parameters as we make these lighting changes or decide to make further lighting changes in the future. That's it for me. So I'll pass it back to Axel.

Axel Pearson: Awesome. Thank you, Hannah. I hope you give tours because I think Jackson Hole is not too far from me and I would really – the pictures alone are great. So very interesting stuff. Thank you so much.

Hannah Bouline: Yeah. We have a virtual tour online. You can also come and sign up for public tours. So you can check out our virtual tour on our website.

Axel Pearson: Awesome. That's great. Thanks. Let's go – yeah. Let's introduce our next speaker again, Derek Allen. Really interested to hear what you have to say about University of Vermont as well. So take it away.

Derek Allen: Yeah. That was very cool, Hannah. Thanks, Axel. My name is Derek Allen. I am the greenhouse facilities director here at the University of Vermont. We're housed in the College of Agriculture and Life Sciences. My team and I manage three separate facilities here. The one you can see in the picture is our main campus facility and it's the most technologically advanced and the one I'll be presenting on. It's really at the heart of the University of Vermont. It's a very popular place on campus especially once winter hits.

Next slide, please. So I just wanna orientate you all to what I'll be discussing here. I wanna touch briefly on our mission here at the greenhouses and then describe some of the details of our facilities and break into our environmental control system. Then I'll wrap up with some of completed equipment projects including the lighting project we finished in summer of 2021 as well as our climate curtain project that just finished in September and then some ongoing and future projects we have planned here at the greenhouse.

Next slide. So the UVM greenhouses are a core facility for the University of Vermont and it's our goal really to support the research, education, and outreach mission of the College of Ag and University of Vermont at large. Next slide, please. So in terms of research we are an R2 research university and I'd say about 40 to 50 percent our main campus greenhouse space is utilized by researchers mainly in the plant and soil science and plant biology

departments. They're asking and answering questions everywhere from entomology and integrated pest management to invasive species, forest modeling, and we also have a well-established fern diversity research hub here at the University of Vermont.

Next slide. Of course we're a university. So a big core component of our mission is education of our students. At last count we have over 20 different courses that engage with the greenhouse including greenhouse operations and management which I teach in the spring semesters, plant propagation, plant systematics is another big one as well as even a botanical illustrations class, which comes in and utilizes some of our conservatory pieces for their art projects. So really cool component for that class.

We also offer internships in the fall and in the spring. They support our conservatory in the fall and in the spring they gain hands-on experience in plant production and sales and prepare themselves for a career in horticulture once they graduate. We also have about six to eight federal work study positions that we open up for students throughout the year. These folks are critical to just the day to day functions of the greenhouse and they're a great group of students. You can actually see in the picture some of my greenhouse operation and management students installing a vertical farm wall and then down below they're taking some light measurements. They have a project to design a light map for the greenhouse.

Next slide. The last piece of our mission is really just supporting the outreach and communicating what we do in the greenhouses to the wider community, the wider public. Like I said, we have a conservatory. It is open to the public Monday through Friday and it's mostly tropical and subtropical species as well as some diversity outside of that including almost about 400 individual taxa. So it's a permanent living plant collection. We open up the greenhouse for tours. So whether it's faculty, staff, we have elementary kids, high school kids coming in pretty regularly, master gardeners taking tours, learning about our research, some of the cool plants we have in the conservatory. We also offer growing advice for folks.

We have an Instagram account that my work study students maintain. They're always posting about some of the cool stuff that's in bloom in the conservatory or some of the research and teaching that's going on. We do have an active plant rental program where departments at the university will rent our plants and showcase that for events. Then a really, really big component of the greenhouse

is we do in-house production and sales since we have a big spring sale where we're growing everything that you might need to start your backyard garden.

In the fall we have an increasingly popular Oddball plant sale where my plant production specialist is propagating plants from our conservatory and we sell them to students for dorms or houses or whatever. Actually, in that top right you can see a long line of students and staff braving the weather trying to get in for our Oddball sale. We grow house plants year-round. Then coming soon a little personal project of mine, we're gonna start growing some native plants. A lot of this just dovetails back into our education side of things 'cause none of this would get done without all the students we have on hand.

Next slide, please. So a little bit about the main campus greenhouse facility. It was built and opened in 1990. So we're over 30 years old now and we do have some aging equipment, which we'll discuss as this presentation goes on. It's 8,000 square feet of controlled environment growth space all under glass. It's divided into – I have 11 different compartments, two of which are small air conditioned houses. Each house has its own independent environmental control systems. So I can tailor each of those individual environments to whatever crop or species of plant I'm growing to achieve maximum success.

I mentioned the conservatory. Two of our compartments is about 1200 square feet. It houses our permanent living collection of over 400 individual taxa from plants just from various corners of the world. We do have an outdoor nursery. It's about 2,000 square feet that we use about 7 to 9 months out of the year. Next slide, please. So let's get into the more interesting meat of it. Our environment control system, the original install was our QCOM environment control system and we upgraded a few times. In 2015 we replaced that system with the Argus Titan environmental control system and this actually predates my time. We've been running with that for seven years now. It's done really well for us.

Much like in Hannah's case, it monitors and automates the greenhouse equipment using real time data from censored data collected internally and from the external weather station. This ultimately controls our HVAC system, our lighting as well as our climate curtains which allows us to maintain ideal temperatures, ideal humidity levels, and ideal light levels for the target crop that we're growing in each individual compartment.

And more specifically what interests me the most and what's been the most useful is this piece that it's recording all this historical trend data and it stores it and I can use it to analyze and figure out where things might be going wrong with some research projects if I need to finetune the data. It's also – this historical data has allowed me to make strong cases for modernizing some of our really aging pieces of equipment. So the rest of this presentation is just going through some of these pieces of equipment that we're trying to replace and increase energy efficiency.

Next slide, please. So the first project I wanna talk about is our lighting upgrade. This LED lighting upgrade was completed in the summer of 2021. I took over in early 2020. When I came on we were at a critical low point for the amount of light that we had. Many of our aging HID fixtures were no longer working or some of them were 10 to 15 years old and they had a poor level of energy efficiency. So there's definitely a need there, especially to improve our research capabilities to push for more lighting.

So in the fall of 2020 I applied and received a grant from the UVM core facilities upgrade fund to purchase 18 fluence high efficiency LED light fixtures. After some research and looking at our needs and the diversity of plants that were growing, we really needed something that was more broad spectrum. We didn't wanna target any specific spectrums 'cause as my researchers come and go their needs change. So the broad spectrum allowed us to have a diverse approach to our lighting needs. These two have a 2.7 micromol joule efficiency.

So for those of you who might not be familiar, if you're in the market for LED's, the industry standard is you really shouldn't purchase anything under 2.5 'cause that's just basically not giving you enough light for the amount of energy you're putting in. These are tested and listed and certified by the design lights consortium. So throughout the process of applying for this grant, I went to the Burlington Electric Department and based on data that my predecessor had given them, this was Argus data that we had collected over the past several years before my time, they based the estimates on 1,500 annual operating hours.

For those of you that are familiar with growing in the northern latitudes, that's extremely low operating estimate. I think it only equates to about four hours a day of lighting, but this is what my predecessor had given them. So this is what we went with for this first round of lighting upgrades. What they estimated was about 12,000 kilowatt per hour annual savings equating to just under

$2,000.00 of annual electric savings and they did give us an incentive of about $150.00 a unit. So total of $2,700.00 for that project, which would equate to about a simple payback of 7.6 years.

Next slide, please. So what do we do with these lights? So my focus is mainly on the research and getting a quality of research higher from what it was in the past. So I installed all 18 of these lights in three separate research houses. Hannah briefly talked about the heating output of LED's compared to HID's. They do produce heat, but not nearly as much as a HID. So I installed a full six of them in one of our air conditioning houses, which you can see here in the picture. Mainly that was to reduce the cooling demand in the heat of the summer. The reverse is true for these other medium size houses.

So I actually did a mix of LED fixtures and some newer model phantom HID high pressure sodium lights that we purchased in a one to one ratio in two of our medium sized houses because as I'll talk later, our shade curtain system is old. It was very old and it's very leaky. We were worried about bleeding a lot of heat off in the winter time and the loss of the HID heat. We weren't sure if that was gonna really increase our heating demand. So we blended them in these medium size houses. I do wanna shout out to the Resource Innovation Institute. We partnered with them.

I gave them access to a couple years of our Argus data and they went through that and analyzed it and just looking at one year of Argus data we found some interesting stuff and what I was estimating we'd be running these lights at. So in the red there you see the original estimate. So we originally estimated about 1,500 hours annual operation, but it actually turned out to be more than double of that. So we ran these lights 3500 hours a year, which actually equated to over 22,000 kilowatt per hour savings over $3,000.00 in actual cash value and electric savings. This actually brings the simple payback down to 4.2 years.

What – again, thanks to resource innovation institute, we were then able to take this information packet to Burlington Electric Company and I've got an in progress lighting project that I'm working on. I'm trying to get 28 more of these LED fixtures and because of this data we were able to collect through Argus we were then able to get them to increase the incentive up more than double. So now the incentive for LED units that we purchased is 370 a unit, which actually brings the simple payback to three years, which in the lighting industry that's huge, especially for our needs.

Next slide, please. So I mentioned our climate curtains. This project was actually just completed in September 2022 and oh, gosh. Where to start? These – our older curtains were over ten years old. The system, the motors, and the cables, it was not designed for greenhouse use. It was giving us a lot of problems. So we actually had to do a full replacement and we did for four of our greenhouse compartments. So it's about 45 percent of our total grow space. We replaced them with the Harmony series from Svensson. Again, we had to do a full gutting of infrastructure and reinstall a new motor and cable system.

So it made the project a lot more expensive than you would if you were just replacing curtains. Original estimates from Svensson and Vermont Gas were estimating about a nine percent increase in energy savings, which would equate to about $1,000.00 cost savings in the first year. So we did – through Vermont Gas they did give us an incentive of $5,000.00, which was nice 'cause it helped cover some of the electrical reworking we had to do to complete this project. I should say, if you're not replacing the entire motor and cable system, you're just replacing the curtains, the actual simple payback would be less than a year just from the natural gas savings alone. Again, ours was a full replacement.

As for phase two, well, that's still up in the air. I am in the process of looking for funding. While I do that, we just so happen to be running an experiment with two of our greenhouses. So exact same climate settings. One greenhouse has the new climate curtain system and the other one has the old, which just bleeds a lot of heat. We just hit winter time now. So we'll be collecting that data all through the winter and my hope is to show one, it increased in the actual estimate from what they gave us, and then leverage that into funding for – to complete the rest of our houses. Next slide, please.

Just real quick I wanna show you one last equipment upgrade. I consider this one really just low hanging fruit. It just makes obvious sense to me. So for those of you not familiar with an HAF fans, a fan that basically distributes air within the greenhouse. Thanks to Argus we were able to go through records and these fans run 75 percent to 100 percent of the year. So it's a heavy electricity user. Some of the fans we have – I think there were 14 fans. Many of them are original fans and they're still working 30 years later. My goal is to replace all 14 of those with a high energy efficiency Schaefer fans, which you can see there in the picture.

Really all I want to show you here in these colored boxes on the right, so this came from the Burlington Electric Department. This project is less than $5,000.00. It equates to a savings of over 17,000 kilowatt hours, which is almost $2500.00 annual electrical operation cost savings. They gave us a very generous incentive which comes to a simple payback of just over half a year. So this is my next project when the next round of grant funding comes up. Next slide. That's my presentation. Thank y'all for your attention.

Axel Pearson: Awesome. Thank you, Derek. Man, I really like to hear that the data collection from the Argus system allows you to get those better incentives. I think that's a really key part to any advanced control system that is either energy monitoring or just collecting data. That's real information that could be used and helps pay off the systems. That's super interesting. So thank you. That's great. All right. Hannah, I see you on the screen too. So that takes us to – let's go to the next slide. So we've got a few questions in here and we've got about six minutes.

So I'll take a few. I'll try to split them up evenly, but give me a second. I'm gonna look over to the question area and I'll try to hit some of these. First question – well, I'll just say, not – one that came in says, "Not a question, but great photos to both of you." So that definitely makes for a good presentation. So thank you for those. Hannah, maybe I'll direct this one to you. Is there a way – how do I pair crop in light spectra? Is there a generic guide to mapping crops to certain light spectra or does it vary by subspecies of crops or anything like that? Is there any advice you can give there?

Hannah Bouline: Yeah. It varies definitely by crop type greatly depending on what your lighting needs are going to be. You can think about daily light integral or you can think about PPFD. A great guide to echo Derek around shouting out resource innovation institute is their best practice guide for lighting in the CEA industry, which I can drop into the Q and A as well. It goes through a lot of the specifics around how to pair lighting intensity with different crop types. I don't think that we're really to the place of necessarily getting so far into subspecies. I'm not typically thinking about one type of lettuce needing more or less light than another, but as we get more data I think – especially with things like artificial intelligence with cameras mapping growth patterns, that might be things that we can finetune when we have data do so.

Derek Allen: Yep. Can I add to that?

Axel Pearson: Please.

Derek Allen: There is a lighting lab at Michigan State University and they do a lot of floriculture research. I believe the head of that lab is Eric Rumble. They publish peer reviewed articles, but they also do these one to two page snapshots for industry growers so you don't have to read through all the jargon. It's really, really helpful. I've gotten a lot of my data on LED's and targeting DLI, Daily Light Integral for certain crops. I got a lot of that information from Michigan State University's lighting lab. They were great.

Axel Pearson: Nice. Good to know. Derek, I think this one came in during your presentation. So the Argus Titan slides seem to show a combination of HPS and LED. Though HPS does not really allow for varied output, I guess meaning it's not dimmable or doesn't dim well like LED's. How does your system mix sources that can dim like LED with static output like high pressure sodium?

Derek Allen: So my phantoms do dim. I can dim them down to I think about 600 watts, but there's a couple of stages in there. I've actually had to because our actual conduit system is old as well. If I run them all on high power they trip my system. So some of these older conduits, I actually have to dim them. Now in terms of combining those, again, I think Hannah mentioned this too. I'm looking at a specific daily light integral that's ideal for my crops and I can then go through my Argus data manually and make sure I'm pinpointing that specific daily light integral.

Actually, this ties into his earlier question about a light map. What I would do is – I actually have one here – is get a nice car censor. So like a light core. You can't see that. There you go. Like a light core censor. It's a work horse. If I need to take data for all corners of my greenhouse to see, but the light levels are there, it's great for managing that sort of thing to make sure my levels are even and accurate.

Axel Pearson: Nice. Okay. Let's try one more knowing that we just have a minute left. I think this is related, but it's reaching the end of my plant growth knowledge. Where did you get growth pattern budgets for better lights? Did you have a table saying plant size or yield based on DLI?

Derek Allen: Is that for Hannah?

Axel Pearson: I think either of you.

Hannah Bouline: I think it's – Derek received grant funding. We also received grant funding for some of our lighting upgrades through the USDA REAP office based on making the case for energy efficient systems and equipment. Most of – a lot of that wasn't based on yield as much. That was part of, I think, part of our internal push is to make – I don't know if we had enough data at the time to equate those things and that's some of the things that we're looking at with the computer imaging is trying to make that case better. A lot more around it was based on just the energy efficiency period. I don't know if you had a different experience with that, Derek.

Derek Allen: I can echo that. What's important to know for us is we're a service unit for the university. We're not meant to make money. So we don't have a surplus budget. So I have to go to some of these internal grants or if I was a commercial grower I'd be looking at state or municipal level grants talking to my utility departments to see what kind of incentives they can give me because they – at least here in Vermont, and I've heard from colleagues across the country, some of these are very amenable to offering generous incentives to update and improve your energy efficiency.

Axel Pearson: Nice. Great. We are at time. Thank you for all of your questions that you answered. I will share an e-mail with Derek and Hannah afterwards and hopefully we can follow-up with you. Let's go one more slide and I'll just bring us home. One more pitch for the Lighting Systems Technology Research Team. We continue to develop resources for industry. We want them to be valuable for you and the best way to do this is for you to get involved.

We have advisory groups and working groups that take specific topics and develop those resources. So if you're interested in getting involved, please let us know. I'd be happy to work with you. With that, I will just say thank you again very much Derek and Hannah. Those were excellent presentations. Thanks to everyone that joined. Feel free to shoot me an e-mail any time and with that, I'll let y'all go. Thank you so much.

Derek Allen: Thank you. This was fun.

Axel Pearson: Take care.

Hannah Bouline: Thanks, everyone.

Axel Pearson: Bye.

[End of Audio]