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Boston Community Energy Study

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Webinar Panelists

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Stephanie Welcome to today's webinar, which is hosted by the Solutions Center in partnership with MIT Lincoln Laboratory. Today's webinar is focused on the Boston Community Energy Study. Before we begin I'll quickly go over some of the webinar features. For audio you have two options. You may either listen through your computer or over the telephone. If you choose to listen through your computer please select the mic and speakers option in the audio pane. Doing so will eliminate the possibility of feedback and echo.

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Finally one important note to mention before we begin our presentation is that the Clean Energy Solutions Center does not endorse or recommend specific products or services. Information provided in this webinar is featured in the Solutions Center’s resource library as one of many best practice resources reviewed and selected by technical experts.

Today's webinar agenda is centered around the presentation from our guest panelist Eric Morgan who has joined us to discuss the Boston Citywide Energy Study. Before we jump into the presentation I'll provide a quick overview of the Clean Energy Solutions Center. Then following Eric's presentation we'll have a question and answer session where Eric will address questions submitted by the audience. At the end of the webinar you will be automatically prompted to fill out a brief survey as well. So thank you in advance for taking a moment to respond.

The Solutions Center was launched in 2011 under the Clean Energy Ministerial. The Clean Energy Ministerial is a high level global forum to promote policies and programs that advance Clean Energy Technology to share lessons learned and best practices, and to encourage the transition to a global clean energy economy. Twenty-four countries and the European Commission are members covering 90 percent of the clean energy investment and 75 percent of the global greenhouse gas emissions.

This webinar is provided by the Clean Energy Solutions Center which focuses on helping the government policymakers design and adopt policies and programs and support the deployment of clean energy technologies. This is accomplished through the support and crafting and implementing policies related to energy access, no cost expert policy assistance and peer to peer learning and training tools such as this webinar. The Clean Energy Solutions Center is cofounded by the governments of Australia, Sweden, and the United States with in kind support from the government of Mexico.

The Solutions Center provides several clean energy policy programs and services including a team of over 60 global experts that can provide remote and in person technical assistance to government and government supported institutions no cost virtual webinar trainings on a variety of clean energy topics, partnership building with development agencies and regional and global organizations to deliver support, and an online library containing over 5,500 clean energy policy related publications, tools, videos, and other resources.

Our primary audience is made up of energy policymakers and analysts from government and technical organizations in all countries. But we also strive to engage with private sectors, NGOs and civil society. The Solutions Center is an international initiative that works with more than 35 international partners across a suite of different programs. Several of the partners are listed above. They include research organizations like IRENA and the IEA and programs like SEforALL and a regional focused entity such as ECOWAS Centre for Renewable Energy and Energy Efficiency.

A marquee feature that the Solutions Center provides is a no cost expert policy assistance known as Ask an Expert. The Ask an Expert service matches policy makers with more than 60 global experts selected as authoritative leaders on specific clean energy finance and policy topics. For example in the area of energy resilience we are pleased to have Michael Milton Wu, principle of Converge Strategies serving as one of our experts. If you have a need for policy assistance and energy resilience or any other clean energy resilience or any other clean energy sector we encourage you to use this valuable service.

Again this assistance is provided free of charge. If you have a question for our experts please submit it through our simple online format cleanenergysolutions.org/expert. We also invite you to spread the word about this service to those in your networks and organizations. Now I'd like to provide a brief introduction for today's panelist.

Eric Morgan is a member of the technical staff in the Energy Systems group at MIT Lincoln Laboratory. And Lincoln Laboratory Eric works on adding renewable energy and energy storage to tactical DOD microgrids and has researched microgrid development for the city of Boston. And with this introduction I'd like to welcome Eric to the webinar. Eric?

Eric Hello, thank you. Should I just start going?

Stephanie Absolutely. We look forward to it.

Eric All right, okay. Well thank you very much for the introduction and thank you everyone for being here today. So a couple of things to start off with—I'll be talking about the Boston Community Energy Study today, also known as the Citywide Energy Study. I'm at Lincoln Laboratory right now. It's in Lexington, Massachusetts. Lincoln Laboratory is a federally funded R&D center but it's funded through the Department of Defense. So we do work for national security technology in support of national security.

So we see microgrids and grid resiliency as being a piece of national security. And certainly with problems like Hurricane Harvey most recently and then Irma and seeing the devastation that occurred after that, how do we bring those communities back online more quickly? And how do we make sure that people are safe after those events happen? And so part of that I'll talk about today in terms of the energy piece.

So can everyone see my slides? All set, okay.

Stephanie Eric, yeah the presentation looks great.

Eric Okay good. All right so let me just start off with the world urban population and electricity use. So back in the 1980s you know the three major countries in terms of population were India, China, and the United States. Each of them had about 150 million to 200 million people in urban centers. Also the United States was using a lot of electricity compare to India and China. And so as we advance by decades here—1990, 2000, 2001 what you see is that people are moving into cities especially in India and China. And in those regions people are using a lot more electricity than they did.

In the United States we're up to about 250 million people in urban centers and we're still using about—I think that's 10,000 kilowatt hours per person per year. So that suggests that you have concentrated people using a lot of electricity. And so what you want to do is make sure that those people that are concentrated in those certain areas can be supported by infrastructure. Well what ends up happening is—at least in the United States this is now a billion dollar disaster and there are a couple more that just got appended to this for 2017.

This goes through 2014. You end up with people in large urban centers that get hit with huge storms, whether that's cyclones or some other severe storm. And then the amount of money that gets spent to compensate for these huge events starts to get larger and larger right? So on the right-hand side is the CPI adjusted losses in terms of billions of dollars. And there are certain spikes. There's a spike for Hurricane Katrina. There's going to be another one for Harvey. There was one in 2012.

But these trends are suggesting that as people kind of concentrate you end up with very costly problems. So one way to try to mitigate some of that is what we call microgrids. And microgrids are—I can read the definition for you here but it's essentially—it's a smaller version of what we consider "the grid," right? Where I am in New England we have a grid that consists of all of the New England states and we can export power to Canada and bring it in from Canada and also to New York.

But a microgrid is a much smaller version of that you know on the say 10 to 100 megawatt scale rather than the gigawatt scale. And so you could add things like renewables, cogeneration, electric vehicle storage, and then interconnect with the utility to create a small system of electrical power distribution. And so when you do that you can increase the security, the stability, and the resilience in the face of outages. And it's actually a fairly cost-effective way to produce power. And it's sustainable because you can incorporate renewables into it.

That's what a microgrid is but there are certainly challenges that we have that are impeding the progress of microgrids on the larger grid right now. How do you interconnect with the grid? How do you make sure that the frequency on the microgrid is the same and the macrogrid when you go to close those breakers? And so there are sort of research questions around that. In terms of what they're providing for resiliency this is a picture of Superstorm Sandy back in 2013. This is Manhattan. And that's Goldman Sachs that's on. They have a microgrid.

So what we're trying to say here in terms of national security is we want to be Goldman Sachs we want to be the building with the lights on when there's a huge disaster. In Superstorm Sandy there were several microgrids actually that were running 11 facilities, about 145 megawatts of power. These included hospitals, places of refuge, municipal entities. Princeton University had one. They were online after a couple of hiccups, but they came online. But what ended up happening in something like the 2003 blackout was half of New York City's hospital backup generators failed.

And we see that in DOD installations as well where DOD installations—a lot of the Army and Navy bases around will have backup generation. But then when they lose power they'll realize that their backup generators don't actually work because they haven't tested them in two years. They don’t have fuel. The mice chew the wires or something like that. So in a microgrid the systems are always on. They're always engaged. You're always kind of making sure that they're operational. So it's a different mindset than having a backup generator.

So I'm going to be talking about Boston today. Let me first just brief what Boston is for those of you that don't know. So it's about 655,000 people in Boston itself, in Boston proper. It's about triple that if you kind of go outside into the beltway area—the 128. Boston itself covers about 50 square miles and has about 84,000 parcels of land and 92,000 buildings some of which you see here. And that's actually getting—the buildings are getting taller and taller. You can be growing in size and population.

So globally what this means is that we're adding three Boston's per week to cities. So that first chart I showed you where people are moving into cities we have to compensate globally for three Boston's every week, which is a lot of people. So if we can solve the microgrid challenge then you know it'll help globally as well. We just had a problem here in Boston. Some of the power went out because a substation failed. One of the Prudential _____ went out. That's the one on the right side. And then the John Hancock Building stayed on. I believe they have some microgrid capability in there.

So some of the Citywide Energy Study objectives: we wanted to look at Boston, and we wanted to figure out where the microgrids and distributed energy resources make some economic sense. Where they support critical loads—critical being hospitals or places of refuge. We wanted to serve vulnerable populations if possible. Vulnerable people would be elderly or poor or anything in between. We also wanted to reduce greenhouse gas emissions. So how do we provide resiliency while reducing the carbon footprint? And we wanted to be able to develop a generic approach that you can use not only in Boston but New York City, Washington, DC, Tokyo—wherever it happens to be.

But in order to do that we really needed to get one city done properly. Some of that was talking to Boson and the government—the utilities, the stakeholders, and the public about what they were expecting from I guess the governments—federal government or local government in terms of adding resiliency. We also wanted to be able to figure out what we needed to—what kind of information we needed for these largescale energy transitions—what kind of data we would use.

So I'll talk about the study approach that we had, the overview, some of the building modeling that was done on MIT campus at the Sustainable Design Lab. And then I'll talk about some of Boston's simulated energy use. I'll talk about what DER-CAM is. DER-CAM is put out by Lawrence Berkeley National Laboratory. And we'll talk a little bit about what CHP means—Combined Heat and Power, and then some of the results that we had. This is just a blueprint of the entire study.

The study it took on our end at Lincoln Labs maybe two months. But there was a lot of work done by my campus prior to that to get the building information correct. So let me just talk about Boston and the building stock that we have here. This is the vintage of the buildings. This is a map of Boston. So pre-1950 building—that's in green. And so you can see it's actually fairly old building stock. There's not a lot of new development in terms of buildings—2010 to present—even though when you go to Boston it feels like there are a lot of new buildings popping up.

Relative to the number of buildings that we actually have in the higher city there are not actually that many new ones. So what we have is an old building stock which means that the insulation isn't great in a lot of these places. The wiring is not great. And so there are heating and cooling issues that we have to contend with. In terms of building types this is a chart that shows everything from churches all the way down to athletic facilities. And it contains a lot of residential areas. So a lot of those green buildings that I showed in the previous chart here—a lot of those green ones are actually residences.

So one to two story, three story housing in Boston itself. To orient you, the airport is the big peach thing on the top right. That's Logan Airport. And then there are various other specialized parcels of land here and there. But this is generally what we're looking at. It's old buildings that are primarily residential. So what campus did was take a look at the energy information for certain buildings. This is another shot of a smaller area just to show you kind of what the resolution is. And the State House is in the middle there.

So what was the modeling done on these buildings by campus? What they really wanted to do was first understand the vintages of these buildings. But they needed to get GIS data for the entire city so they could figure out what the building property type was, how many stories it had, what year it was built, and what year it was renovated, et cetera. They had an understanding of what the building actually physically was. They needed to know things like how high it was above sea level, the structure type, what it was being used for.

That was all of the data that the city actually provided from Boston Redevelopment Authority—one of our partners—on this project. The building geometry was then added. So once they kind of knew how high it was and how many people were in it and maybe something about the windows they could start to add it into a 3D model of the entire city itself. And that was useful for shading and for figuring out—orienting where the buildings are in the city.

From there they can start to take some of the data that they work with in the architecture department—you know shading, building use, how many people are in the building, and generate physical models of what they think the energy use is going to be for each of these buildings. And there's about—like I said—85,000 buildings. And so based on that they came up with an hourly simulated dataset for every building. So now we have 8,760 hours for one year simulated for plug loads, cooling, heating, and hot water.

And the energy it assumes to be the end use, not considering the efficiencies. They're really kind of bringing the city to life in terms of what is being done on energy—for the energy footprint of the city itself. So they were able to simulate all of that data. I'll give you a little sense of what that looks like in terms of 87-60 data. This is District Hall where I gave a talk. So I actually used District Hall's energy portfolio for the year. Plug loads are on the top there. Plug load is anything that you're actually plugging into a socket.

So whether that's a computer or television or a laptop or something like that. Cooling loads would be anything that's air conditioning. Heating load obviously is you're providing heat during the winter, spring, and fall months. And then hot water—so shower loads, et cetera. And this is kind of robotic here. It's essentially the entire city is turning on and off their plug loads at the same time. But eventually what they wanted to do with the data was kind of convoluted a little bit and added a little bit of noise to it. But this is what we were working with at the time.

So I showed you the State House. This is what the State House actually looks like. I've broken this into the different seasons in terms of plug cooling, heating, and hot water. So if you look at the plug loads they're fairly constant across the four seasons. Cooling loads obviously summer and a little bit in the spring. Heating loads are actually fairly interesting. There is much, much higher heating than there is anything else in terms of the power needed for basically every building. So just be mindful that when I talk about energy use we're talking a lot about heating here too—not just electricity.

Some of the study was based on some of the other work that was done in Kuwait. So the folks from campus—Christoph Reinhart and his team—actually tried to figure out what was happening in some of these building in Kuwait. They did a simulated—what they thought was simulated—or a good simulated energy use intensity. But what they found when they actually went to the buildings and walked through is that their models were wrong. They were a little bit off. So they needed to calibrate them.

And so they were able to do that in Kuwait. We did not do that in Boston. We were not able to get actual data for electricity, heat, hot water, et cetera. So just be mindful as we move forward through this that the data that we have is simulated data based on our best guess, but it's not actually calibrated like they did here in the Kuwait study. But there is a lot of information that campus was able to provide. One of Christoph Reinhart's projects was looking at photovoltaic potential in different cities. This is actually a really neat tool called Mapdwell. I believe Google either took it over or made something very similar to it.

But it essentially shows what the potential for PV is on any rooftop in Boston. This is also showing you what the total electrify demand is in a typical day in Boston. We have some of this data also is what the PV would look like. So based on kind of all of the data that we were given from campus the question is what do we do with it? What are we going to look at? And so let me just show you downtown Boston here. This is—to orient you a little bit—

Massachusetts General Hospital. It's actually one of the largest energy users in the city.

And this is Faneuil Hall downtown. I'm looking now at the energy intensity of the buildings in kilowatt hours per square meter per month. And so it goes from almost nothing which is some of these vacant lots to a significant energy use. And this is a movie. I'll try to—I think it's going to be a little bit jerky over the webinar but I'll play a little bit here. This is January. That's February. We still have pretty high energy intensity. We'll keep moving through here. That's March, April. I'll stop it there. April it starts to come down.

So April is one of these shoulder months where you don't really have heating and you don't have that much cooling yet. And so it's essentially mostly electricity that's being used. So the entire city is actually at a low energy use level in April. That'll start to come back up as we move into the summer months. I'll move it into May and June. June here is really starting to do the cooling. This is all electricity but there is no heating right now. July again we're starting—moving to cooling. This is September and October.

October doesn't have any heating yet. Oh boy—sorry about that. If I can get my mouse back I'll show you the end of the video. But at the very end of the video it's essentially the same with January where you've got almost all heating load occurring in the city itself. So November and then December. That's what we're contending with. In terms of the statistics for the city on the left-hand side it's got the building stock. That's the type of the building and the amount of floor area that we have. And then the energy data is just the rest of it.

So total energy—gas, electric, plug, heating, cooling, and hot water. What we see here is that the residential is over 90 percent of the buildings but in terms of total energy it's less than half. Things like offices in blue represent under 10 percent—you know 5 percent of the total buildings. But in terms of total energy they're somewhere in the 20 percent range. In terms of electric they're using something like a third of the entire budget for the city.

There are other interesting features here. The medical labs—that is like the hospitals for example—they represent almost none of the buildings in the entire city—a very, very small number—like 10. But if you look at their floor area they've got a significant amount of floor area. Their total energy use and their total cooling use is very, very high in terms of what the city is using. And hot water—We should just note here that hotels have a lot of hot water usage—on the very far right on the top there.

In terms of the heat map for the city this is hours per day on the X axis and day of the year on the Y axis. This is just showing that in June like I said it's a shoulder month. So we're only using something like 250 megawatts of energy or power in the middle of the night. This is 2:00 AM in the morning on June 8. Whereas you contrast that with—by the time you get to January—January 23rd at 8:00 AM in the morning everyone is waking up. Everyone is turning on their lights. Everyone is taking a shower. So we're at 8.2 gigawatts of energy there.

So orders of magnitude difference in terms of how much is being consumed in the city. And we expect that this is fairly similar in many of the cities that have heating loads like this, so a lot of the northeastern cities definitely. It's probably different if you go down south to Florida or let's say Arizona. So let me talk about DER-CAM which is what we used to—So we took all this data. We had all this data. We have knowledge of where all these buildings are in the space.

But we needed a way to kind of collect all that data and make recommendations about where we would put a microgrid if we had to invest money in microgrids. So DER-CAM is what we used to help us with the decision making. Distributed Energy Resources—Customer Adoption Models put out by Berkeley National Lab. It's a mixed integer linear program that optimizes for a couple of things. It'll optimize for total energy costs or carbon dioxide, or it can do both simultaneously. But what it needs is exactly the information that campus provided us which is heating, electric, hot water, and cooling.

So let me just talk about some of the populated equipment costs we put in. So we didn't have an exhaustive review of every single type of equipment that we had that could be put into a microgrid. We put in what we thought would be the most useful: micro turbines, combustion turbines, internal combustion with combined heat and power and hot water. And then there are some other ones here including diesel, et cetera. So this just shows the cost of the equipment.

And we have upfront capital costs and that's kind of ongoing costs for O&M and over the lifetime. So for the flowchart this is what DER-CAM is essentially doing. We're giving it the utility and the resources—the local resources—for fuel, et cetera. So we're giving it all the costs for the fuel and all the costs for the electricity and everything else. And then we're giving it the demand and some of the constraints that we are imposing on it. Then giving it the list of technologies that—We want to kind of sweeten those technologies for the optimization. And then it'll give us the optimal planning and operation answers from that.

So like I mentioned before we're looking at three microgrid types. Today I'll mostly talk about multiuser microgrids. But we did for the study—You can find the study on the internet. The Energy Justice microgrids which would be kind of affordable housing kind of propping up the folks that are poor or elderly and then emergency microgrids where people could go if there's a problem. But I'm going to focus on multiuser microgrids today. These are mixed use, high density areas that usually include an anchor building and have some critical facilities attached to them.

So for the microgrid modeling analysis the way that we started it was we took the building data from campus. We tried to find anchor building—that is large buildings that high loads that we could build a microgrid around. We then would group buildings around those anchor buildings. We would look at the thermal footprints for those buildings. That is looking at kind of the heating loads that they had. And that's heating in terms of both air and water. We would also look at some of the energy usage and some of the constraint around the anchor buildings for the buildings near it.

We would put all of that into DER-CAM along with the utility costs, the regional greenhouse gas mix from the bulk grid. And the DER-CAM would give us what it thought were kind of the baseline costs. What was happening prior to an optimization? What it thought the costs were in the greenhouse gas emissions would be for that set of buildings that we _____ for that grouping. Then it would give us the optimized version. If were to create a microgrid that was cost optimal what would that look like, and what kinds of assets would be involved in that? And what would they cost?

And then a microgrid that was greenhouse gas optimized: what the assets looked like there and how they were used. From there we could take the information that DER-CAM provided and get microgrid rankings. That is terms of cost, in terms of greenhouse gases and in terms of the mission. That is it a multiuser microgrid? Is it an affordable housing type microgrid? Or is it a critical—still with these types of microgrids?

So before I go on I want to just kind of briefly touch on what combined heat and power is. I have mentioned this is the past couple of slides. But combined heat and power—you see it a lot on campuses. MIT has one. I believe Princeton has one. My alma mater at UMass Amherst has one. And it's essentially using the fuel twice. You use the fuel for generating electricity. But then you take that waste heat and you recover it. And you can send that to steam or heating loads.

So some of these combined heat and power plants can be on the order of 80 percent efficient whereas if you've just had electricity it's usually on the order of about 40 percent efficient. So we're really doubling the amount of energy that's extracted from the fuel which is where we want to be. In terms of national security, again we don't need to be burning fuel for no reason. That would mean that we'd have to go get more. And whether that's going to the Middle East to get it or somewhere else there's always a national security concern if we're wasting energy.

So let me talk about some of these building groupings that I mentioned here. So the top .2 percent of the building energy use is shown here. So this is the top users of energy in the city itself. This is where we decided we should look at building microgrids. That is we would pick one of these buildings—one of these parcels of land—and then try to determine what was near it that we could kind of leverage for the microgrid. So Logan Airport is on there. That's the big one on the top right. That's not the best place to run a microgrid although they probably already have one.

So the multiuser microgrid screening algorithm although we were looking at—Again we picked the building in the middle. That's the anchor building. And then we signed the CHP plant for 60 percent of the peak electric. So that is if the peak electricity is 100 megawatts—and that only happens for you know 5 minutes a year—we're going to size the CHP plant for taking 60 megawatts. That's the size of it. We're going to assume that 40 percent electric generation efficiency—we're going to assume the spark spread meaning the amount of money that it costs for me to generate electricity versus buying electricity is actually positive.

That is it makes sense for someone to do this. That was actually $70.00 per megawatt hour in Boston at this time. We're going to kind of radiate out from that center building in 50 meter increments and we're going to pull in all of the buildings in that circle that you see. And we're going to design a CHP plant around those buildings. So can those buildings take some of that excess heat from the CHP plant? Do they have the right heating load or heating profiles to take the heat from the electrical generation? And were not selling anything back to the utility grid here.

We could do that but the city did not want us to look at something like that. So in terms of the building rank now this is a plot that I put together that shows the building ranking in terms of energy size or energy use and then the distance away from those buildings. And what we're looking for here is a thermally matched portfolio. That is we can always get rid of our heat. It's always hard to get rid of—to guarantee it's easy to make electricity. So we're looking for places that can take the heat.

So if you kind of go through this fire plot it's the things that are more white that we would pinpoint as the places that we should run a CHP plant. Places that are black have no thermally matched time. That is there is never an instance where the buildings can take some of the heat from the CHP plant—that excess heat. And then there's everything kind of in between. So really pinpointing a lot of the places that have these white bands here that you see—places like this—some place to take the heat.

Let me just talk a little bit about the critical facilities and affordable housing before I move on. So this was one of the layers that the city wanted us to look at: so some of the supermarkets, pharmacies, gas stations, emergency shelter, and affordable housing are on here. Now certainly in Hurricane Harvey and other Hurricanes these are the places that people need to go. People have to go get gas even though there's a shortage of gas. That's a problem too. But having gas stations that are open is always a challenge. But it's great if you can do it.

Having access to pharmacies where people can get the rugs that they need, emergency shelters, and supermarkets for people to get food. So these are some of the other layers that we could consider if we really wanted to. Some other constraints are that there are actually in Boston already some microgrids. So we don't want to recommend putting a microgrid where there's already a microgrid. So Harvard University has one. MIT has one. The Museum of Fine Arts in Boston has one. But also this kind of big grid in the middle here—the is the Veolia Steam System.

So there's actually already an existing steam system that can move heat around in Boston. The question is can we actually leverage that with a microgrid? The answer is unclear at the moment but that's the type of information that we really wanted to know prior to recommending any microgrids. So let me just talk about some of the results from DER-CAM after having all that data that I discussed. I showed you the picture of—let's go back here—this zone here—Zone 118. What does that look like?

When we ran that through DER-CAM it's essentially recommending in terms of we've got the cost optimization here and then CO2 optimization. It's recommending that we put in a fairly large CHP plant. This is in kilowatts—so 1,000 kilowatts—but something like a 5 megawatt CHP plant in terms of cost optimization. We kept the PV and the solar thermal at 100 kilowatts each just because we were—We had constraints for the roof. But it recommended the most it could recommend for both of those. It really actually likes air source heat pumps.

If you look at the economics of those it's essentially an air conditioner running backwards. So it's actually fairly good for heating. And then it's recommending absorption chillers here also for this particular microgrid. And on the right-hand side for energy storage it's recommending some heat storage and then some cold storage. So for the CO2 optimization things are a little—The story is slightly different but not much. The CHP plant is a little smaller and the air source heat pump is a little bigger. The heat storage is a little smaller. And then there is no cold storage for that.

This is the same microgrid 118. The base case is shown in green. So at the time of base case there was no onsite electricity. So that's why it's zero in the middle there. And moving clockwise around the annual costs—And if you look at cost optimizations, CO2 top 2 optimization and the base case the cost optimization beats the base case. The CO2 optimization does not. But they're all fairly close. For total C02 emissions as you would expect the base case is worse than the other two. That's because we've added you know PV storage.

We've added some new technologies to the mix to kind of reduce the energy portfolio. But it also reduces the CO2. In terms of utility fuel consumption we're using a lot more fuel onsite for the cost optimization. That is we're burning more natural gas onsite to produce electricity. The CO2 optimization does not do that. In fact it's saying because the grid is decent you should be buying more from the grid. Offsite CO2 generating—you can see that the CO2 optimization is better than the base case but not by that much. And for utility electrical consumption we are buying almost nothing from the utilities for the cost optimization. For CO2 optimization we're buying a little bit less than the base case.

So this is just kind of giving an example of what some of those outputs are from DER-CAM and how we can use them and what we should be looking for an actual microgrid. Once we took kind of all the data from campus, put some of the constraints in place, race the DER-CAM program, got some of the outputs I just showed you, we kind of started to develop a map of where the best places where for putting the multiuser microgrids. Those are in red. So we picked I believe it was 12—Is that right? Twelve multiuser microgrids in various places across the city that were kind of the best use cases that we could find.

We picked some affordable housing. A lot of that is kind of in the Hyde Park area of Boston. Then we picked some for critical facilities. They're emergency microgrids. So places that we would choose to put a microgrid that was not only affordable or reduces the greenhouse gas emissions but also would be good for the community itself. That is if you have a Hurricane Sandy or Harvey type of event these places would be open for business. And they would stay open. And so the city was very interested in having places that they could explore for that.

So this is just recommendations—kind of a prescreening tool. The city then actually went to these communities and put some boots on the ground and looked for places that they could actually implement these microgrids. And they're starting to go down that path now. Some of the multiuser microgrid outputs that we get from these models from DER-CAM show that if you're interested in cost optimization there are certainly savings that you can get. And the bigger the CHP plant, the bigger the microgrid, the more savings you get.

In terms of CO2 optimization it's kind of split. You're not really saving that much money on some of them. Or you're losing money on some of the other ones. But you're reducing greenhouse gas emissions. If that's more valuable to you than saving $1,000.00 a month or several million dollars a year then maybe you should pick that option. Or maybe there's some combination of the two that can be explored here. Like I said DER-CAM does do kind of the dual optimization. And you'd expect a dual optimization to fit somewhere in between these two lines for cost and CO2 optimization.

We did run some of the Energy Justice microgrids as well. So a lot of those are essentially break even. There's actually one outlier for cost optimization. For CO2 optimization if you're just looking at Energy Justice—that is the places that are good for the vulnerable populations—for CO2 optimization you end up losing money. Now maybe that's what you want to do but you can certainly do that. So what are some of the next steps here that we wanted to explore?

Another study was done a couple of years ago. So we've had kind of ongoing discussions with different entities in the country for what we should kind of do next. What we really want to do is integrate additional GIS information into this model. This model was really like a proof of concept. Now can we actually take data from the city and do something useful with it—make a meaningful recommendation? But it was slightly restricted. Even the city doesn't know really where their electrical lines are—utility lines are. We don't really know what the loads are in the substations.

So on the distribution level we don't really understand not only where the physical lines are but how much capacity they have, what the substation's loads look like. We don't really know that much about the natural gas pipelines. We have some information about where they might be. But this is an old city. Boston is old. So you go out to the—You talk to the utility folks and they don't even know where their own pipelines are sometimes. And that also includes some of these steam lines. You know where do those sit?

We were up in Springfield, Massachusetts and they have legacy steam systems out there that they were running in the mid-1900s. They're still sitting underground but they're not being used. So there's some talk about revitalizing some of these older infrastructures that we have available. But the other things that we kind of want to overlay is some of the criticality and vulnerability analysis using the GIS data. We didn't really quantify how a vulnerable population would benefit from having a microgrid. There is no metric that we could point to that says yes you're going to be less vulnerable by 20 percent.

But there are some metrics that are emerging in academia and government that might start to point to that. And really what we want to do is kind of run a similar analysis in Boston or somewhere else that has real calibrated building data so that we know—have a better confidence about what we're saying so when we recommend a microgrid, the calibrated data, this is where you should really put a microgrid. And we'd be right about it. So just as a summary we pioneered a city scale energy assessment.

This has really never been done before. It's exciting to do. Identify 22 sites with about $1.7 billion—with a B—dollars in potential savings and then about a 25 year period. We established this framework that's applicable to any other region. So whether that's Boston or San Francisco or somewhere in Germany you can still do this with this type of analysis. But kind of moving through the process we've identified some of these data needs. And more importantly maybe is the stakeholder impact.

Stakeholders could be the folks in government in the city itself. It could be state actors as well. But it's really the people that own the buildings or live in the building and the utilities that have to come on board and kind of rethink the way that they approach energy systems. Right now most of the time energy systems work great. They're not that expensive. But when there's a large problem everything turns off. That's really not where we want to be in terms of national security.

And in doing—kind of talking to the stakeholders we kind of developed these relationships with the public and in Boston that would really help expedite some of these projects in the future—some of those lessons that we learned, these softer skills—that we're not used to actually at Lincoln Lab. It's kind of push these projects forward a little bit. And we've demonstrated here—well it's on paper—that microgrids are economically environmentally viable in Boston and likely in other places as well. I just wanted to mention some of the partners.

We worked with DOE on this one, Massachusetts Clean Energy Center, Boston Redevelopment Authority. The Sustainable Design Lab at MIT, Department of Homeland Security, and then Berkeley National Lab. These are the folks that kind of worked on the project. I led the project on the Lincoln Labs side, Travis Sheehan on the Boston Redevelopment Authority side. So if you got to the BRA website—I think they have a different name now so maybe we can send out the new website. But there are reports that were put together by the BRA and by us and by MIT Sustainable Design Lab that you can read through and see kind of some of the details that I glossed over a little bit.

And that's all I had for today. So I guess we'll move on to questions if that's the next phase of this.

Stephanie Yes Eric. Thank you. Thanks for that outstanding presentation. As we shift to the questions and answers I just want to remind the audience to please submit their questions using the question pane at any time. During this we'll keep up several links on the screen for quick reference that point to where you can find information about upcoming and previously held webinars and how to take advantage of the Ask and Expert program. We've had some great questions from the audience so far so I'd like to begin.

Eric is there time of use and demand charge for commercial customers applied in Boston?

Eric No. We did not do that. That's something that we want to do in the future with this type of project. I think some of the subtleties on that one were that we didn't really have great access to some of that economic data, but we should have. You know it's something that we definitely want to get our hands on. And I think since we've done this program—the Citywide Energy Study—we have been able to engage with ISO New England and kind of get some of those numbers.

Now the other piece of this that I didn't mention was that the city itself—You know they commissioned us to do this study. But they were very wary of having this look negative to the utilities. So some of the demands charges or some of the time of use charges that we're talking about we did not incorporate into the model on purpose so that utilities would kind of have a softer blow if you will for the impacts—economic impacts. So I hope that answers the question but certainly there is definitely more research to be had here. It was kind of a proof of concept if you will.

Stephanie Okay, very good. How are the differences in the electricity charge rate included in a mix of building electricity cost analysis?

Eric Yeah so we did have some discrepancy there. We had pricing for industrial, commercial, and residential. And we knew what types of buildings we had. So we could really break out some of those different price categories. And those were all included in the model. Like I said we didn't do demand charges or any time of use charges or anything like that. But we did have some level of fidelity on the pricing. But then once DER-CAM pulled all that information in it was able to optimize with the numbers that we gave it. And we could give it any other numbers too if we had more data.

Stephanie Okay. We've had several questions from the audience about how you came up with the 60 percent for the CHP sizing and the 40 percent for energy efficiency.

Eric

Yeah so those were basically rules of thumb for CHP plants. So there's not much literature on it but if you kind of go to some of the—I guess the utilities that do this—those are the numbers that they actually use for their rule of thumb. And that's kind of what I—I'll call it a prescreening. You really want to be able to do—to offset some of that thermal energy. But those were the numbers that we found people are using.

Stephanie

Okay, very good. The data that was used in the simulation was not validated. How did this affect the model?

Eric

Yeah so we don't really know. That's the problem. If you look at some of the data that we have it's very robotic. That is everyone in the city is turning on and off their lights at the same time. And so that presents some interesting trends if you will in the city itself. What you would expect to be in a city is that there is a distribution or probability that someone is going to turn on their light at any given time. But it's not exactly at the same time. And so in terms of the energy use it probably—We're probably close.

In terms of the power profile we might be close. But in terms of kind of the hour to hour, day to day energy management it starts to get a little bit murkier. We're probably pretty good on the monthly or yearly scale. But the daily to weekly scale is definitely different. So we really want to get the calibrated data. That was something we tried to work with the utilities to get and we were just never successful at getting that. And some of that is for privacy issues. You know you don't want to be giving data away to us essentially if you're the utility because there are folks that are—I guess you can discern some patterns of behavior from it. So there's some sensitivity there.

Stephanie

Okay. Did your analysis consider the required square footage for the equipment, PV arrays, turbine feeding systems, fuel storage, et cetera?

Eric

So we assumed that it could be put in the basement of somewhere. And whether that's a great assumption or not I'm not sure. I think that if you look at some of these older buildings they do have large basements. But we didn't necessarily say you know you have to have this much square footage for a CHP plant. And the reason for that was that a lot of those CHP plants that we were looking at were not large. That is they're less than 100 megawatts. So we felt that in terms of square footage we wouldn't really need that large of a footprint to get the job done.

I should note also that the city really was not interested in showing some of these CHP plants would be off-putting a lot of CO2. So we didn't run them as hard as we probably could have run them given the footprint size that they had. But I'll just mention that as an aside. So the CO2 levels that were actually coming out of them are a little bit lower than they should have been.

Stephanie

Okay thank you very much. The next question is have you thought about doing this in other cities?

Eric

Definitely. And we are definitely open to doing this again. We've talked to folks in San Francisco and New York City about doing it. We've thought about doing it locally here in Massachusetts again just to have a municipal utility work with us to get better data. But you know we're definitely interested in doing this somewhere. Like I said we kind of trail blazed a little bit here just to try to understand what we didn't know and what we needed to know. And so I think the second generation or the second city that we would do we've had a lot more institutional knowledge of how to get this done, what kinds of impacts it would have in terms of the community, and really national security.

And as you can see microgrid—In the last couple of years microgrids have been discussed more and more and more. We had some symposiums here at the lab on microgrids. And so we're getting more and more engagement there. We're definitely engaged with the other universities around the nation just to kind of push microgrid. We're engaged with microgrid for tactical spaces, whether that's Afghanistan, Iraq, or DOD bases. So there is a lot of involvement from Lincoln Laboratory and microgrids, and this is just one of those pieces that we really wanted to grow.

Stephanie

Okay, thank you. The next question from the audience is does the CO2 optimization model include any types of federal or local incentives for renewable energy or just the cost of local marginal price?

Stephanie

Local marginal price. So we didn't put any—We kind of stopped there and that's probably one of the criticisms is that we didn't take into account the cost of the carbon dioxide. So I think the Boston Redevelopment Authority—they took our numbers that we gave them—the raw data. And they were the ones that actually put the economics down onto those numbers. So what we tried to do is stay kind of neutral and say this I how much we think you can reduce the energy or the CO2 just based on the equipment, not necessarily on anything else.

And the costs were energy costs, and in capital cost for the equipment. And then the city could then take those numbers in terms of how much CO2 reduction we had an add their own kind of metric on top of that. And so if you go to the reports that they issued for the Community Energy Study you'll see the calculus that they had for that. Jon Lee was the one in the economics department for the Boston Redevelopment Authority that started to put some of the numbers together. And so when you look at kind of the social impacts or the climate impacts, et cetera, for the CO2 it actually turned out to be fairly significant.

If you're saving CO2 you know how much the city is saving. And I forget the numbers now. It's been a couple of years since I read those reports. But there were billions and billions of dollars that were being saved in terms of CO2.

Stephanie

Okay thank you. The next question is: were there any other technologies considered besides CHP? And if you could further go into about how other options were weighed for comparison?

Eric

Yeah so we did put a—It has a giant—DER-CAM has a database of—in probably—in terms of the bulk power grid—I don't know, maybe 15 or 20 options. So it had fuel cells in there. It has micro-turbines, diesel gen sets, and internal combustion engines. We put solar PV. I think we added geothermal as a possibility. And so we didn't really restrict what it could do. It just turned out that CHP was kind of a winner. And there are some good reasons for that I would say. Like I said it's 80 percent efficient and natural gas prices at the time were fairly low.

And I think they're still low—all of the fracking. And we could go into how far down the rabbit hole we want to go in terms of water use for fracking or where the natural gas is coming from. But we did not do that. We tried to keep it fairly technology-agnostic. That is we put what we thought the costs were for the different equipment. Keep all the equipment in there and just let DER-CAM tell us what the best solution was given the database. So it does have solar PV, solar thermal, batteries were in there, cooling storage, et cetera.

But the city of Boson putting solar for example on the top of these high rises it's just kind of a mismatch in terms of the geometry. It's true that you can produce electrical power on top of the Prudential Center for example—on the 100^{th} floor. But relative to the Prudential Center which uses somewhere in the neighborhood of 10 megawatts you're probably only going to get maybe a couple hundred kilowatts out of it. And there are also shading issues in major cities. So PV was an option but it was not the best option.

I think that answers the question but I'll again big a plug to Mapdwell. If you're interested in solar power check out www.mapdwell.com. M-A-P-D-W-E-L-L. com. And that will show you what some of the data was that we put in fo0r PV panels.

Stephanie

Okay thank you Eric. Our next question was: was there any consideration for outage, natural disaster, and actual island operation time?

Eric

So not really for this study. We have other programs at the lab that consider that type of thing. For this we're basically assuming 100 percent uptime. That is if you have a microgrid first of all where would you put the microgrid? And that's kind of what this analysis was. We did look at the floodplain a little bit—you know if this is going to get flooded or not. Do we want to put a CHP plant or substation where it's flooding? Definitely not. So there were some layers there that we kind of screened by hand. But we didn't have anything like outages or anything like that in the model.

This is a prescreen model. And you kind of pick the candidates—the 22 candidates that we had here. And then you would kind of do different analysis after that. Some of them got screened out just because of floodplain issues or other issues.

Stephanie

Thank you. The next question is: is a microgrid control standard needed for better standardizing microgrid designs?

Eric Yes. And we're working on a tactical microgrid standard here at the lab—tactical microgrids being anything that kind of the DOD uses I guess. In general I think IEEE is looking at that. And we are on some of the working groups. I'm not involved in that. Some of my colleagues are. Eric Limpaecher is probably the first and foremost person here at the lab that's pushing for these standards. So what you don't want is to have a lot of different microgrids that have different control systems and different control algorithms.

In terms of bulk utility grid you really want everyone when they close the contractor to reenergize or reconnect with the grid. Everyone is on the same frequency. The voltages are kind of—Everything is sorted out. You don't want any problems when you reconnect. And some of that is black starting basically part of the grid. So we're looking at doing some black start analysis with microgrids right now. How would you take disparate microgrids in the city of Boston and actually connect them together? What kinds of standards do you need to do that?

What kinds of controls do you need to do that? We have an adjacent program here at the lab called the hardware-in-the-loop program that we actually take simulated microgrids in Simulink or MATLAB and we hook them up to real hardware controllers, woodwork controllers that think they're controlling a real microgrid. And we basically run the simulation and have the controller control it. And so there are actually some interesting dynamics that happen there when you've got lots of different controllers and lots of different options.

You don't want emergent behavior from some of these controllers. So how do you manage the standards there to make sure that there's none of this emergent behavior? Make sure that the frequency and the voltages are all set before the contactors are closing.

Stephanie Thank you Eric. For our final question of the webinar did you explore smart grid style microgrids? And also an essential microgrid controller will supervisory control over the lighting, heating plugs, loads, et cetera?

Eric What was the first part of that? Sorry.

Stephanie Oh I'm sorry. Let me repeat it. Did you explore smart grid style microgrids?

Eric Smart grid? I guess I'm not sure what that means per se. But no there was no smart grid I guess infrastructure embedded here. We have talked to campus about doing something like that—which I think is the second part of your question. The microgrid controller that we were kind of thinking of for this study did not control lighting. It did not control the buildings. That would be the second layer that we want to add on to it and kind of an adjacent study. If you took one of these microgrid areas and then you had building controllers that could turn off and on air conditioning, cooling, or lighting, et cetera, you could really start to change some of those load profiles that I showed.

And change some of the demands. And then have the micro grid controller interact with that controller. So that's kind of double-controlling it, but I think there are definitely benefits there. And certainly the macrogrid does something like that where they're doing demand controls. So they'll turn off—You know they'll have different buildings or different entities sign up to turn off when there is high demand. Prisons will turn off or municipal buildings can turn their loads off. And that'll just manage the grid a little bit. We could definitely do that in some of these buildings.

We're definitely interested in having kind of this dual control use where we control the building and then control the microgrid and iterate. We have not done that yet but we're definitely thinking about doing that.

Stephanie Thank you Eric for the informative question and answer session. For any of the questions we didn't get to—and we got a lot of great questions today—we'll connect with those attendees offline after the webinar. Now I'd just like to give Eric an opportunity to provide any additional or closing remarks before we end the webinar today. Eric would you like to wrap us up?

Eric Sure just thank you everyone for being here today. I assume my e-mail address will be available. If you have any questions for me directly just please contact me. Like I said the lab is very engaged in this area right now. And so we're interested in partnering with utilities, commercial entities, et cetera—other laboratories around the country—to kind of push some of this technology forward. Thank you very much and have a nice day everyone.

Stephanie Great. Thank you again Eric. On behalf of the Clean Energy Solutions Center I'd like to extend a thank you to Eric and all our attendees for participating in today's webinar. We very much appreciate your time and hope in return that you had some valuable insights that you can take back to your ministries, departments, or organizations. We also invite you to inform your colleagues and those in your networks about the Solutions Center resources and services including no cost support through our Ask an Expert service.

I invite you to check the Solutions Center website if you'd like to view the slides and listen to the recording of today's presentation as well as previously held webinars. Additionally you'll find information on upcoming webinars and other training events. We are also now posting the webinar recordings to the Clean Energy Solutions Center YouTube channel. Please allow about a week for the audio recording to be posted. Finally I'd like to kindly ask you to take a moment to complete the short survey that will appear when we conclude the webinar.

Please enjoy the rest of your day and we hope to see you again at future Clean Energy Solutions Center events. This concludes our webinar.