[Pre-webinar conversation]

All right. Welcome. Thank you so much for all of you who could join us today. This is webinar number nine in our online learning series. It's really been a wonderful collection of interesting topics that we hope you guys are getting a lot out of Today's topic is Process Heating and Waste Heat Reduction, which I know at least on the Better Plants side, a number of our technical account manager were particularly excited about the topic that we cover. Next slide. So that's me. Eli Levine. I'm delighted to have you all join us today. Next slide.

And just as a reminder, this is session number nine. Last week, we had a great one covering about pumping and fan systems. And before that, we had kicked off the second round of our online learning series talking about energy treasure hunts, virtual treasure hunts, the resources that EPA covers, our resources. So I encourage you once these are posted to go back about watch the recordings of them, as well as for the first six as well. They really are a great resource. Next week, you know, fingers crossed, we're hoping to have an exciting weapon are about a new pilot initiative that we're hoping to launch on field validations, so looking at new technologies and the role that DOE and the Better Plants program can play in validating these new technologies, proving their savings and de-risking about the potential in your plans to adopt them.

So there's a tiny asterisk there just based on when our colleagues and public affairs make the announcement next week. So it if anything changes, we'll be sure to let you know, but, otherwise, we really look forward to having you join us on Thursday for the for the webinar. You can ask questions about the new pilot that's being announced. And then just take note of all the other upcoming webinars. If there any topics that we haven't covered that you would like to see us cover, 50001 Ready, or, you know, water or waste, or any other topics, just please let us know and we were happy to add to them. We like to do them about six at a time just so as not to overwhelm your calendars.

Next thought. As in previous ones, we're really excited to have the capabilities of Slido as a way to ask questions. So please go to www.slido.com, #DOE, and within there, you'll see our webinar and get in your questions there. And our presenter can answer any questions. And you can – even if you don't have questions, you can upload any questions that you particularly like to make sure those are covered. Next slide. So the agenda today, as we mentioned, Sachin will be walking through the process heating and waste reduction, and then taking your questions using Slido. So it should be a really good, a really good webinar today. Next slide.

And with that, I'm going to turn this over to Dr. Nimbalkar. I'll say that we, as in previous webinars, we had Sachin go ahead and record himself ahead of time just to make sure the webinar could be delivered without any technical glitches or children in the background, as we're all dealing with now. It's also a way for us to make sure we're confining Sachin to the 75 minutes we've allotted him, although he's promised me now that he's going to open up with a story that wasn't part of the 75 minutes. And even when we try to limit his time, he finds creative ways to keep getting his message out.

[Laughter]. Sachin, I'm just testing you. But with that, thank you for offering to do this and for lending your time and your expertise to this topic, and I'll hand it over to you.

[Change to Primary Speaker]

Thank you. Thank you much, Eli. And, also, Marissa, Leslie, Clifton, thank you so much. I think any day, you know, any day when I get an opportunity to talk about process heating, it's super exciting. I really become very happy. So thank you for this opportunity, Eli. And so Eli is right. I like to talk. And so I'm glad we recorded this. I want to limit myself to 75 minutes. But, you know, many times, people ask me this question, like, "What's the most interesting, exciting part of conducting assessments on process heating systems?" And, of course, we are going to learn about process heating systems during this webinar. So the answer to that question is I actually have, in fact, a small story. The answer lies in a _____ bag.

My first process heating assessment, I actually conducted that assessment at an iron and steel facility a long time back with my mentor Dr. Vin Dectee and Dick Bennett. Some of you, a few of you probably know Dr. Vin and Dick Bennett. They are definitely topnotch. They are definitely topnotch process heating experts. And so I'm conducting this process heating assessment in iron and steel plant, and then I'm looking at this large reheat furnace along with the recouperator. And so the recouperator was larger than the furnace. And so I'm looking at reheat furnace and then this recouperator, really large recoupment.

And I'm looking at my software tool, process heating assessment and survey tool, and I'm asking this question to Arwin, "Is this going to ever work?" You know, look at this equipment. You know, it's like a large size, and tremendous amount of natural gases burned. And then now we're going to model this equipment, develop a kind of heat balance analysis on this equipment in this software on our computer. Is that even possible? And but in testing things, we were able to do that. We measured oxygen level and temperature of exhaust gases, and we were able to immediately start our analysis.

We were able to quantify thermal efficiency of that furnace, available heat, and we were able to identify a new efficiency approach by the end of that day. So very powerful. And, of course, we tested that, that software tool at the same time, this, this, this, heat transfer, thermal dynamics, basic heat transfer algorithms, not only in the US, but we then traveled to China, Ukraine, Brazil, all different countries, and it works. *[Laughter]*. It works. So without further ado, I think let's look at this, you know, this specific topic, improving process heating system and then also we'll talk about waste heat recovery today. So, Marissa, let's get it started.

The title of this webinar is Improving Process Heating System Performance and Wasted Management Options. Typically, we cover these two topics separately as there is so much to cover. But for today's webinar, we are going to try to cover both topics in approximately 60 minutes. In this graph, we are showing system opportunities. In, in any manufacturing plant, we are dealing with process heating, steam systems, electric motor systems, pumping systems, and then compressed air system. And there are other systems.

For example: lighting. In this graph, they're showing in a typical manufacturing plant, how much energy is consumed on different systems. And as you can see, process heating and steam systems consume almost 60-80 percent of energy. Again, this is based on Energy Information Administration Manufacturing Energy Consumption Survey, EIMECS. So every four years, they publish this statement. And based on that, uh, we know, typically, process heating and steam systems consume a significant amount of energy.

Now, in the bottom, we are showing potential energy saving opportunities. And as you can see, process heating and steam systems, there is actually significant energy savings potential, 10-30 percent. And, of course, other systems, similar situation. But as process heating and steam systems consume a significant amount of energy, 10-30 percent of energy savings potential is significant amount of energy. So what's why process heating system is important.

So what is process heating? Process heating, actually, in a nutshell, in simple words, is supplying heat to materials in different type of equipment. So there are basically furnaces, ovens, heaters, thermal oxidizers, dryers, boilers. So those are process heating systems. And what they're doing is we are applying, we are using heat energy and we trying to make something or we are trying to heat or dry some materials. So that is process heating.

Now, this diagram is also based on DOE's EIMECS. Energy Information Manufacturing Energy Consumption Survey. And this is based on 2014 data. And what it shows is basically manufacturing energy and carbon footprint, and this is based on all manufacturing sectors. So NAIC score 31-33. What it's showing is onsite energy use on manufacturing sector level is roughly 15,000 trillion BTUs. And so all that energy, roughly 15,000 trillion BTUs is actually coming in the manufacturing sector, and that energy is used for onsite generation, process energy, and then non-process energy.

And then if you look at process energy, we are consuming a significant amount of energy in process heating system, process cooling and refrigeration, other processes uses, electro-chemical and then machine drive. Machine drive includes pumps, fans, compressed air, machine handling, and other systems. But if you look at process heating, a significant amount of energy, actual retrieval and then steam electricity is used for process heating. And then almost 2,556 billion BTUs up in energy is wasted. So whatever energy, a significant amount of energy going in, but, at the same time, almost 32 percent of process heating energy in the entire manufacturing industry is wasted. That is all lost.

So if we look at, if we try to understand our process heating system on a little bit of a micro level. So what's happening, right? So if you look at combustion-based process heating system. Combustion-based means what they're doing is they're using natural gas, oil, or coal as our energy sources. We are burning those fuels and we are generating heat energy. So in the combustion-based process heating system, we are burning fossil fuel. We are generating heat and energy, and then that heat and energy is applied to product or charge material. But at the same time, we have controlled volume around that process heating system. And our goal is to keep that heat energy within that controlled volume. But what's happening is a lot of heat energy is going out and is actually wasted. And so some of that heat energy is not recovered at all. So that energy is going out and it is completely wasted. And then some portion of heat energy is recovered using waste heat recovery opportunities. Okay?

So we have this control volume around our processing system. Heat is generated. Heat is transferred using conduction, convection, radiation to product or transfer material, and there is tremendous amount of energy going out of your control volume. And what we're trying to do is we're trying to use this heat energy to heat, melt, dry, or cure something. Okay? Now, in the center here, they actually recommend a significant resource work in making these process heating systems smarter. And so that's why we have the sensors and process controls. And more or more, we are adding smartness to these systems.

So now if you look at a electricity-based process heating system, what you will see is there is no significant difference between combustion-based and electric-based system. Electricity currently presents only five percent of the energy used for process heating in US manufacturing. So almost 95 percent is we are using fossil energy, so natural gas or coal. Electricity is only five percent. But there is not a significant difference. So if you have electricity, what you are doing is you are generating heat energy, and then you are transferring that heat energy to product or charged material in the form of, again, conduction, then convection radiation.

And the way you generate electric energy is you use resistance or ionizing radiation, non-ionizing radiation. But all other components are the same. There are also heat losses in electricity-based processing system, but generally those are less. Now, what happens is when you consume one kwh of electricity on site, you are almost consuming three kwh of energy, whatever natural gas at the remote power plant. So site two source conversion factor for electricity is significant. So, somehow, if you actually get renewable electricity or low-carbon electricity, then the system efficiency of your electricity-based system is higher.

Now, let's look at major areas for energy savings potential in process heating system. So, again, we are dealing with combustion-based process heating systems or electricity-based process heating systems. In both cases, we are dealing with a different type of losses. And as you can see in this Sankey diagram, our fuel input is coming in. So this is gross fuel input, and then we have net fuel input, and then available heat. And then that available heat is actually used to basically heat your load/charge material. So some heat and energy is useful. Useful in energy. Okay. That whatever heat and energy going to your load/charge material, that's actually the best use of that heat energy.

The problem is some portion of available heat is consumed by these different losses. So we have wall losses, radiation losses, or cooling water loss, conveyor loss. Some heat and energy is stored within the structure of your furnace, and then heat leakage losses, and then other losses. So what's happening is only certain percentage, only certain proportion of heat and energy, available heat, is actually used for useful purpose, but then a lot of available heat is wasted. And then we also have fuel gas losses or exhaust gas losses. Now, the difference between gross fuel input and net fuel input is basically your heat energy going out in the form of water vapor. Because when you combust natural gas, or methane, propane, you're generating a lot of water vapor now, and then you lose heat and energy in the form of that water vapor. Okay?

Now, how to improve this process heating system, right? To improve process heating system, what you want to do is minimize all these different losses, and then make sure most of the heat energy is going to be your charge material. And at the same time, you want to minimize fuel gas losses. And so there are ten different major areas for energy savings potential in process heating system. The first one is optimizing heat and energy going to your load/charge material. Then material handling, so whatever fixtures or trays you're using to take charge material inside your furnace. So optimizing that material handling system and minimizing heat loss in that material handling system is actually very important.

The third one is heat supply, heat generation. So what we want to do is whatever fuel you're consuming, whatever electricity you're consuming, whatever heat and energy we are generating using fuels for electricity, we want to keep that heat energy within this controlled volume, itself. We want to keep most of that heat energy inside the furnace. So that's actually called purpose heat supply or heat generation. The next one is furnace exhaust and heat recovery. Again, we want to minimize furnace exhaust and then whatever heat energy is going out in the form of flue gases.

And the other areas are furnace-oven walls, so minimizing heat loss from furnace walls. Furnace openings and doors. Water or air cooling. Then optimizing using best control system. Then minimizing wasted energy in auxiliary systems, and then also other losses. But because we have limited time in this webinar, we are going to only focus on these three major areas for energy savings potential. So load/charge material, heat supply, heat generation, and then current one we're going to focus today is furnace exhaust and heat recovery. Those are major heat losses. And this Sankey diagram, for example, showing what happens to your gross heating input. So gross heating input coming in and then significant amount of heat is going out in the form of exhaust gases.

And you can see this graphic in this pie chart, almost 41 percent of heat energy is going out in the form of flue gases. And then only 47 percent going to charge material. And then we have all other losses. So the whole thing is, this is an example of reheat furnace. Okay? So reheat furnace is a significant amount of the energy is lost in the form of exhaust gases. And then we have water cooling losses, opening losses, and then other losses. Okay?

Between 2006 and 2011, DOE conducted almost 300 industrial assessment at large plants, so iron and steel plants, glass-making facilities, or insulation-manufacturing facilities, poor manufacturing plants, chemicals plants. So we kind conducted a lot of process heating assessments between 2006 and 2011. And so _____ _____ assessments. We had actually put together these top ten process heating opportunities. So these are top ten process heating recommendation, okay, based on those large plant assessment. And in this table, we are showing, we're providing a list of this top ten frequently identified process heating opportunities. And then on the right-hand side, they're providing a range and energy cost savings identified, and energy cost savings identified, and then a range of payback period actual. So these are years. Okay?

And as you can see, most common opportunity into process heating system is reduce oxygen content of flue gases. Then use up flue gas, keep for combustion air preheating. Proper insulation and maintenance of furnace structure and parts. Reduce-eliminate openings and air leakage in the furnace. Load or charge preheating using heat from flue or exhaust gas, or other, so, similarly, there are other opportunities. So these slides will be made available after this webinar, so you should be able to look at this table more carefully.

So similar to large plant assessments, DOE's industrial assessment centers also conduct one or two-day energy assessments in small and medium-sized manufacturing plants all over the US. Okay? And so based on those assessments, we have identified top ten process heating recommendations at small and medium-sized manufacturing plants. And so, again, this data will be available for you after this webinar. So, as I mentioned, today, they're going to focus on these three major areas of energy use or losses. Okay?

So the first one is load/charge material. Then second, we are going to look at heat supply/heat generation, furnace exhaust and heat recovery. Okay? This table is showing a range of energy use as percent of the input. And so, for example, load/charge material typically in process heating systems, 15 to 75 percent of total energy input going in is consumed by – is actually used by load/charge material. And there is actually this wide range because we are dealing with different type of process heating equipment. So, for example, electrical hot furnace, blast furnace, basic oxygen furnace, reheat furnaces, handling furnaces. So different level furnaces.

And depending on type of operation we have, depending on different type of loses, you get different kind of thermal efficiency. Okay? And range of energy savings, again, significant savings are ranged zero to 25 percent per load of charge material, heat supply, heat condition, improving combustion system, electric system can actually provide you zero to 50 percent in energy saving. So, again, significant range. The same thing with furnace exhaust and heat recovery is zero to 50 percent. So significant energy savings potential in these three different areas.

So let's start with load/charge material. And so what are different opportunities? How we could improve heat delivered to load/charge material? How we could actually maximize that, right? And to do that, we have multiple pathways, multiple strategies. Okay? So first strategy is, for example, hot charging of the load where possible. So if you take this example, like reheat furnaces in iron-steel manufacturer.

So at the caster, once we have the slabs or blooms, those are hot, right? Because after casting, that material is still hot. So if you take those hot slabs, or blooms, or billets, and then take them directly to your heat furnace and then raise the temperature to whatever your temperature you want, and then do downstream processes, then you're going to save a tremendous amount of energy. But what happens, typically, is after casting, after caster, what they do is with the slabs, or blooms, or billets, they store outside in ambient conditions.

And depending upon the demand, the downstream demand, depending upon product demand, then they bring those slabs, and then they reheat them again in reheat furnaces, and then they do downstream processes to produce coins or bars, rebars, right? And so dropping temperature to ambient, and then again reheating those slabs to whatever, reheat furnace temperature, you consume a significant amount of energy. So you can actually save that energy by streamlining that operation, by hard charging those billets or slabs.

The next strategy is preheating of the load/charge material. Now, you can do that – you can preheat load/charging material using external preheating or internal preheating. Okay. So external preheating, you can use heat from furnace flue gases. So whatever exhaust gases you have using heat energy in those to preheat charge material going in, you can actually then save a lot of energy. Or using axillary preheating, for example, many places, if you have electrical hot furnaces, and if are you making scrap metal in electrical furnaces, what you do is as you are storing scrap metal outside in open field, and if you have snow or rain, what's happening is you're bringing snow as water along with that scrap.

And then you put that in electrical furnace, one, you are wasting energy to melt that snow or water. But at the same time, it's very dangerous because molten metal and snow, they do not go well together. Sometimes, you'll see explosions. And so what they do is they use axillary preheating. They use natural gas burners to preheat scrap metal before it goes in your electrical hot furnace to melt that snow or remove that moisture, right? So that is called auxiliary preheating. So there are multiple ways you can preheat your load/charge material and improve thermal efficacy of your process heating system. Same thing, drying or moisture removal.

Then charging at or near design capacity and frequency. So if your design capacity of your reheat furnace or _____ furnace is, let's say, 110 per hour. So charging – taking whatever raw material you have, and charging at or near design capacity is going to improve thermal efficacy of your furnace. The same thing with proper load arrangement for optimum heat transfer. The whole idea is that within your furnace, you want to improve convection, radiation, as well as conduction. Right? And so arranging your products or load material in such a way, you'll get maximum convection radiation to optimize heat transfer. That's very important, too.

Here is an example. For example, load preheating. In this case, what we are doing is if you look at this is old flue closed. This is old chimney, and exhaust gases. And so load is moving from left to right. Right? It's going left to right. And then exhaust gases are going from right to left. So what old operation, what are you doing is you are taking exhaust gases up old flue. But then what you can do is you can add this additional section. So heat recovery section. Now what you have done is you close this old flue. You take these exhaust gases, hot exhaust gases for your charge material or your load, and then you take those exhaust gases out.

So what you are doing is you're transferring whatever heat energy available in exhaust gases to your charge material. And by adding this heat recovery section, and you're preheating your charge material before it goes in your actual furnace. So potential energy savings by implementing this kind of strategy is typical at 15-20 percent. Okay. For example, 15-20 steel to reheating furnaces. So there's a significant improvement, right, in thermal efficiency.

Here is one more example. In this case, what we are doing is we are using hot temperature pressure exhaust gases coming out of electrical hot furnaces to preheat scrap metal going in your electrical hot furnace. So, typically, electric hot furnace operation is a batch operation. But what you can do is you can purchase this steel convertor, actually a different type of scrap for heating systems. One example is ion steel conveyor. What you can do is your scrap metal, scrap is moving through this belt. So this is actually a conveyor belt, and there is a tunnel, and these exhaust gases are very high pressure, almost 3,200 Fahrenheit, sometimes. Your exhaust gas temperature goes up to 31, 32-degree – 3,200 degree Fahrenheit. And in your exhaust gases, you also have carbon monoxide/hydrogen.

So whole idea is you combust all that carbon monoxide and hydrogen. You increase the pressure of exhaust gases, and then you transfer that heat and energy to stat going in your electrical furnace. So, almost, your operation becomes continuous operation rather than batch operation. And so what we have seen is if you actually, if you increase scrap temperature using this kind of conveyor, if you increase scrap temperature from, let's say, 390-degree Fahrenheit to roughly 1,100-degree Fahrenheit, the amount of electric energy needed for melting the scrap drops by an additional 15 percent.

So, for example, if your scrap going in your electrical furnace is at 600-degree Celsius or 1,100-degree Fahrenheit, you are almost reducing electricity consumption by 20 percent, 22 percent. So significant energy savings possible. At the same time, your electrical furnace operation becomes continuous operation. There are additional benefits, too. And then in terms of example calculations. So in this calculator. we're showing load preheating aluminum furnace. So this is gas-fired aluminum furnace, and you can have a $32,000.00 by a year savings if you preheat your charge material from 82 degrees Fahrenheit to 400 degree Fahrenheit.

So in this furnace, your charging rate is 4,000 pounds per hour, and this is aluminum. And baseline temperature is 82 degrees Fahrenheit, and you are preheating your charging material to 400 degrees Fahrenheit. So new condition is 400 degrees Fahrenheit. So with this kind of change, what is happening is you are almost saving $32,000.00 per year. So that's a significant cost savings, right? So if you summarize, for example, somebody brought load/charge related measures is – so these are different actions basically to increase or to optimize heat and energy going to your load/charge material, and then these are potential energy savings. So, for example, hot charge lower very possible. You can save almost probably to 30 percent of energy. Okay? And so these are other actions, and then potential energy savings.

Now, next measure area for energy saving opportunity in process heating system is your combustion system energy saving measures for your combustion system. And so if you look at combustion system, you are dealing with different components. So you have burners, and you actually – you are combusting fuel. You are using air for combustion. So fuel-to-air ratio is actually important. And so there are multiple components associated with your combustion system. And so optimizing your combustion system is also very important. And you can improve what outcome efficiency by optimizing your combustion system.

So, first of all, what is combustion? The rapid oxidation of a fuel using the oxygen in the air resulting in the release of energy. So that is a basic definition of combustion. Rapid oxidation appear, and you're using air for oxidation, and you are generating heat energy. Now, you can actually combust, you can burn your pure energy three possible ways. One is by using exact amount of energy needed to combust everything. Whatever hydrocarbons you have. Typically, there is a certain amount of air needed to complete combustion. We call it stoichiometric combustion.

Now, if you actually use excess air, then complete combustion, whatever air needed for complete combustion. If you're using excess air, that means additional oxygen in exhaust gases. Okay? So it is called excess air combustion. And then the third one, third situation is you are using less air than stoichiometric ratio. That means less air than whatever air needed for complete combustion, then you are using excess fuel. So you are losing the pure energy in the form of exhaust gases. So you're basically generating carbon monoxide, right? So you cannot do complete combustion. You are losing valuable heat energy.

So it is very important, in certain cases, to maintain air-to-fuel ratio in such a way, you achieve either minimum excess air or you are trying to stay very close to that stoichiometric ratio. Anyway, so combustion system efficiency is very important. And you can do that using proper burners, using proper fuel-to-air ratio control system, by using preheated air. So if you are actually preheating combustion air using some waste heat, now amount of heat energy generated is going to be more if you're combusting the same amount of fuel. Or if you want to generate certain amount of heat energy and if you're bringing preheated combustion air, then amount of fuel energy needed is going to be less.

Fourth option is use preheated fuel where possible. In certain cases, preheating your fuel, for example, blast furnace, gas, or natural gas, you can actually do preheating. But natural gas, for example, it is not typically recommended to do preheating of natural gas. Use oxygen-enriched combustion air, and then use an alternate burner control system, for example, pulse firing to extend the operating range, turn-down ratio. Okay. So there are multiple ways you can improve efficiency on your combustion system.

By the way, what is turn-down ratio? For burners, this is definitely for burners, our turn-down ratio is literally at comparison between muonium to minimum heat output. So turn-down ratio compares the maximum to minimum heat output. For example, let's say turn down ratio is 25 as to one. So what it means is turn-down ratio for direct gas-fired burners is 25 to one, which means that the burner can modulate from four percent to 100 percent of coal fire. So 25 to one means the burner can modulate from four percent to 100 percent of coal-fire. So higher the turn-down ratio is better for energy efficiency. It's better for – you achieve greater energy efficiency. You have better control. Okay. You can modulate your burner with very fine changes, very minute changes. Okay.

So higher the turn-down ratio is actually you get better control for your burners. Okay. So that's one thing you should keep in your mind. Now, excess air control. So there are different – by the way, there are different ways you can control fuel-to-air ratio. Again, for complete combustion, we need stochiometric amount of air. We need a certain amount of air. Right. And so if you have better fuel-to-air ratio control systems, you can achieve whatever you need. So depending upon your load in your furnace, if your furnace is _____ lower, you can actually increase our turn-down ratio. You can actually run your burners at maximum heat output. When you need less heat energy, then you can actually reuse heat output from those burners. Okay.

So fuel-to-air ratio control systems are very important. And, again, there are different types of systems in the market. The most basic one is, for example, incinerators. Incinerators, they give you turn-down ratio four as to one, then cross-connected ratio regulators mechanically-linked control valves. But mechanically-linked control valves are used in boilers. They give as much 40 to one as to one turned on ratio. Okay. And then even better option is electronically-linked control valves. They give, you again, 40 to one turned on ratio. And the best one is pulsometer mass flow control. That gives you 20 as to one. But better control over fuel-to-air ratio.

So, again, what is turn-down ratio? Turn-down ratio basically compares the maximum to minimum heat output. Okay. So excess air control is very important and there are different important strategies related to excess air control. Now, let's look at effect on excess air on available heat and heat loss. So as you can see on left-hand side on primary Y-axis, we have percent of gross heat value that is available. Gross heating value that is available. So this available heat. Okay. And then try to remember the Sankey diagram. We actually saw that Sankey diagram all the way in the beginning.

So in the Sankey diagram, what is shows is you have gross heat going in, but then you have exhaust gas losses. So if you subtract exhaust gas losses from gross heat input, you get available heat. So that available heat is available to provide heat and energy to charge or load material. And at the same time, take care of all the different type of losses; water loss, water cooling loss, future losses, right, opening losses. So this is available heat, and then we have percent losses. And then on X-axis, we have percent combustion air. So this is from zero onward, it is percent excess air. And if you go _____ X-axis, it is percent efficiency of air.

And as you can see, for certain exhaust gas temperature. Let's say exhaust gas temperature is 1,000 degrees Celsius. So as you increase oxygen level in exhaust gas, what it means is if you now use more and more air than needed, if you have excess air, if you're using excess air for combustion, what happens is more and more excess air, you are going to have more and losses. And then for same amount of excess air. Let's say you have 40 percent excess air. Right? Forty percent excess air.

So if you have 1,200 degree Celsius, at 1,000 degrees Celsius, exhaust gas temperature loss is almost 60 percent. Okay? So 60 percent loss at 1,000 degrees Celsius fuel gas temperature. Now, if you actually drop your gas temperature to 650 Celsius, so 1,000 to 650, then your loss actually goes down from 60 to maybe 55, right? So you can actually minimize exhaust gas losses by maintaining close to stoichiometric amount of air, and by losing exhaust gas temperature. Keeping exhaust gas temperature lower is actually important.

So here is an example. Energy savings. Reduction of excess air. So in this example, we are looking at a furnace with 20MMBtu/hr firing rate. So 20MMBtu/hr. It's actually a large furnace. And then current flue gases, you have oxygen in flue gas, eight percent, and then flue gas temperature is 1,200 degrees Fahrenheit. So fuel gas temperature, current, 1,200 degree Fahrenheit. Current oxygen level is eight percent.

And what you do is by after burner tune-up, leak check, and then sealing of the heater, you basically drop oxygen level and exhaust gases to three percent. So from eight percent to three percent oxygen level. Then, certainly, your available heat goes up, and fuel savings are roughly 13.4 percent. And if you look at, if you use $5.00 per MMBtu for natural gas, then savings are almost $100,000.00 per year. So these are significant savings going from eight percent oxygen to three percent oxygen.

So let's summarize our combustion system related measures. And so combustion system related measures work with these different actions. Use proper burner type. Use proper air to fuel ratio control system. Use preheated air. Then use oxygen-enriched combustion air, and then use alternate burner control system to extend burner turned on if necessary. And then potential energy savings in this second column.

Now, number four. Energy savings measures exhaust gases or fuel gases. So, again, what we saw based on DOE's large plan assessment, a significant amount of energy savings we identify in the form of recovering wasted from exhaust gases. So exhaust gases, there is a tremendous amount of heat energy, you know, is going out in the form of those exhaust gases, right? And we want to minimize that. So what happens is if you look at these exhaust gases, there are a lot of different things in exhaust gases. Depending upon type of fuel you're using, you are going to see combustion products, water vapor, liquid vapors, then volatiles, condensable solids, non-condensable particles. So there are basically different types of products that are going out in the form of exhaust gases.

And so they, typically, impact your fuel gas analysis. Typically to measure thermal efficiency of furnaces, we use flue gas analyzers. And when you are measuring oxygen level and exhaust gases, carbon monoxide level in exhaust gases, these condensable solid gases volatilize, they actually impact your flue gas analysis numbers. So when we are taking these measurement, we need to be careful. Okay?

Now, to measure how much heat and energy is going out in the form of exhaust gases, typically, we need to collect, we need to measure two things. One is oxygen level in exhaust gases. And then second is temperature. So oxygen and temperature. Those are two important measurements. Now, where should we make those measurements? So, again, depending upon type of furnace and type of equipment, you're going to collect oxygen and temperature at different locations.

So in this case, for example, top left system, in this system, we not using the recouperator. So this furnace is without a recouperator. So in this case, you can just measure combustion air temperature that is going to be typically ambient air temperature, and then fuel gas temperature. And then same thing, oxygen in combustion air and oxygen in exhaust gases. So you measure those two, and you're good to go to quantify available heat and how much, what percent of gross heat input going out in the form of exhaust gases. You can measure. You can quantify based on those measurements.

Now, if you have a system with recouperator, then things become a little bit complicated. So here, actually, a rule of thumb. So if you have a recouperator, now, we want to measure O2 level and temperature, right, in exhaust gases. So what we do is we use this rule of thumb, low-low or high-high. So what it means is, so, for example, if you measure fuel gas temperature before recouperator, it's gonna be high temperature, right, higher temperature compared to after recouperator.

So if you're measuring flue gas temperature before recouperator, that is going to be high flue gas temperature, what you should do is combustion air temperature, you should measure it after recouperator. That means before that combustion air is used for combustion, so hot combustion air. Basically after recuperating, it gets hot, right. So you should use – so option A is using flue gas temperature before recouperator, and then combustion air temperature after recouperator. So what it means is high-high.

And then other option is option B is if you're measuring, if somehow you're not able to measure flue gas temperature and oxygen level in flue gas or exhaust gases before recouperator, what you need to do is then you need to measure oxygen and temperature of flue gases after recouperator. So temperate of flue gases is going to be lower after recouperator. So low, so what you need to do is combustion air, you're going to use ambient air temperatures. So low-low. So combustion air temperature lowering, and then flue gas also low. And then it is very important to measure flue gas oxygen and temperature simultaneously at the same location. Very important. Okay.

So, again, you will have these slides after this webinar, and you can easily view these specific slides again. Now, the whole idea is, what you want to do is reduce flue gas losses. And how will we do that? There are two possibilities to do that, right? One is we want to reduce exhaust gas temperature. So lower the exhaust gas temperature, you are going to see lower exhaust gas heat loss. So, for example, if, let's say, we have – we are using zero percent excess air. So at 2,000 degree Fahrenheit exhaust gas temperature, your fuel gas loss is almost 60 percent. But then if you drop that temperature of exhaust gases by recovering by using recouperator, or by using air preheater, or economizer, if you drop it to 1,000 degrees Fahrenheit, certainly, now, your loss is only 35 percent. So lower the exhaust gas temperature. Lower is going to be your exhaust gas heat loss.

And then same thing, for same exhaust gas temperature, we want to keep oxygen level in exhaust gases lower. What it means is less excess air. So lower the excess air. Lower is going to be your exhaust gas heat loss. For example, 1,000 degree Fahrenheit, exhaust gas temperature at zero percent excess air, your loss is 35 percent, right? But if you have 150 percent excess air, your loss is going to be 60 percent. So lower excess air and lower exhaust gas temperature are actually needed to reduce fuel gas losses.

Now, let's say you have a certain amount of heat energy in exhaust gases. Now, how to manage that wasted heat. So there's the options. That's why they're calling it waste heat management. It's not just wasted to recovery or wasted to recycling. Waste heat management can use all of the options. So waste heat reduction, waste heat recycling, and then waste heat recovery. So the best thing to do is if you have waste heat in your exhaust gases, the best thing to do is somehow lower or reduce that waste heat within the heating system, itself.

Second option then. If you're not able to reduce waste heat, then try to recycle waste heat within the heating system, itself. And then third option is waste heat recovery. The idea is waste heat recovery means using waste heat from one system in other system. So, for example, using waste heat from one system to generate steam in other system. And then using that steam for something else. Or using waste heat for power generation. That is also waste heat recovery. Okay?

But waste heat recycling is better than waste heat recovery. The reason is if you are recycling waste heat within your system, what's happening is when your system is running, you're generating waste heat. And you're using, you're recycling that waste heat within the same system. So it's actually a perfect match, right? Supply and demand. So supply and demand of heat energy point of view, waste heat recycling is better option. Exhaust gas waste heat reduction.

So let's start with waste heat reduction. So how to reduce waste heat. Okay? And as you know, basic equation for heat and energy calculation is M dot CP del dot T. M dot is mass fluid, and then del dot T is your temperature. So reducing mass flow rate of exhaust gases, and then reducing temperature of exhaust gases. Those are two different ways you can reduce waste heat going out of your system. Now, how to reduce mass flow rate. So reduce or control excess air for burners. So lower the excess air, we are going to have lower mass burn rate of exhaust gases. Higher excess air means you're bringing just excess air, and taking heat energy out of your furnace. That's not good.

The same thing, control make-up air. Whatever make-up air you're bringing in, controlling that is very important. Why you need make-up air? Because if you are dealing with volatile or any compounds, VOCs, and nasty stuff in your furnace, then you need make-up air. You need dilution air, right, to make sure there's nothing in your exhaust gases. Everything is burned, and your diluting your exhaust gases using make-up air or dilution air. So controlling make-up air, reducing or eliminating air leaks. So whatever air leaks have, maybe fixed openings or variable openings, or whatever leaks you have, fixing those is really important. Then reducing moisture contained exhaust gases where possible.

Maybe in certain cases, particularly if you're burning natural gas, if you're burning clean fuel, what you can do is use condensing economizer to basically condense water and exhaust gases, and then recover that heat energy, right? So reducing moisture, whatever moisture going in is the best thing to control that. Okay. So that is one more study. Then process specific actions. Pretreatment of charge material. Use of oxygen-enriched air. Use of air and/or fuel preheating is actually great to reduce mass-flow rate.

And then reducing temperature of exhaust gases. What different strategies are there? So use of proper temperature controls. Use of advanced controls to optimize zone temperature. Then avoid over-firing of burners. And then controlling air-fuel ratio. And here is the summary for exhaust gas reduction related measures. So these are different control strategies we discussed, and then these are typical things. Exhaust gas waste heat recycling. So as I mentioned before, waste heat recycling means using waste heat within your same system. So here are five different options. Okay? Five different waste heat recycling options.

Option one is combustion air preheating. So you need combustion air in the same system, right? So what you can do is use exhaust gases from your heating system. You can use to preheat your combustion air, so air preheater, using air preheater to do preheating of combustion air. And then using that preheated combustion air within your own system, within that same system is actually a perfect example of waste heat recycling. In this second example, what they're doing is using exhaust gases from your heating system to preheat load. So load or charge material preheating. Again, because load and charge material, they're going in the same system, so you are recycling waste heat within the same system. Right? So that is your second option.

Third option is internal heat recycling or cascading. So in this case, what you are doing is you have your heating system, exhaust gases going to thermal oxidizer. And then now from thermal oxidizer, you can recycle, cascade hot gases back in your heating system. So hot gas recirculation, and then you have exhaust gases. And then option four and five, the logic is the same. Technology and hardware are the same. The only thing is in this case, number four, we are preheating make-up air, and in number five, we are using waste heat for water heating.

Now, in this case, this is actually a good example. Preheat combustion air with recouperator. There are different ways you can preheat combustion air. So in this case, we are using recouperator. And recouperator, what's happening is there is actually a physical barrier that separates exhaust gases and oil combustion air coming in. So combustion air is coming in, and this is our recouperator, and then hard gases, exhaust gases are going out. And we are transferring heat and energy from exhaust gases to this combustion air, and then we are using combustion air with our fuel energy. And we are using that preheated combustion air for combustion. Okay? So this is _____ _____.

In this case, we are preheating combustion air using either self-recuperative radiant fuel burner or self-recuperative direct-fired burner. So what self-recuperative? Well, this idea is we are bringing fuel for our combustion, and then we also need combustion air for combustion. But what we are doing is whatever exhaust gas is generated, whatever hot air, hot exhaust gases in your furnace, we are taking them out through your burner, through this – what is a self-recuperative burner, that is taking these exhaust gases out. And as you are taking those out, we are then preheating combustion air going to your burner. So we call this self-recuperative direct burner or radiant burner. They are just different design. The principle is the same. You are using exhaust gases that are going out to preheat combustion air going in.

Here is another. In this case, we are preheating combustion air with regenerators. And so as you see, these are regenerative burners. So regenerative burners, they use typically ceramic materials. So there is actually ceramic bars or ceramic balls in these regenerators. So there are two regenerative burners on this system, completely opposite to each other. Generally, we use multiple regenerative burners. On left-hand side, maybe four-five, on righthand side, maybe four-five regenerative burners. And the idea is what we do is we start, for example, air is coming in. We are doing combustion of fuel. And then hot gases, hot exhaust gases going out through this opposite burner. So the hot gases are going out.

And then after a few seconds, after maybe 20 seconds, after a few seconds, we switch. Now, combustion air, ambient air is going in through this burner, left-hand side burner, and then hot exhaust gases are coming out of righthand side burner. So what happens is as heat energy is stored in that ceramic material, you know, inside this regenerator, we have heat storage materials, like ceramic material. And so then we transfer that heat energy from ceramic material to combustion air, and then we use preheated combustion air for combustion. And then we continue this cycle. Okay? And it is actually shown in this graph, in this time temperature graph. For example, we are showing cyclic nature of heating/cooling, heating/cooling of these regenerative burners.

And here is an example calculation. So combustion air preheating savings. So in this case, if you look at current situation, we have combustion air temperature 60. Sixty degrees Fahrenheit. And then new situation, new scenario, combustion air temperature is 600 degrees Fahrenheit. So rather than 60 degrees Fahrenheit, now, combustion air is at 600 degrees Fahrenheit. And then if you look at fuel savings, we are almost 13 percent savings. And that is equal then to roughly $23,000.00 savings.

Now, here is actually the summary of exhaust gas waste recovery heat options. Waste gas recovery heat options. Recovery. So we discussed so far waste heat reduction options, waste heat recycling options. But because of time constraint, we do not have sufficient time to discuss waste heat recovery options in detail. But the idea is waste heat recovery, what it means, the idea is using waste heat from your current system, whatever furnace you are dealing with, using waste heat from that system in other system.

So example is using waste heat for steam generation, and then using waste heat for hot water heating, plant or building heating, absorption cooling system, and then cascading to lower temperature heating processes. And so these are different waste heat recovery systems, and then typical install cost, typical applications, and then waste heat temperature range. Okay? So all that data is provided in this table. Because of time constraints, we do not have sufficient time to discuss all these systems in detail.

So waste heat to power application consideration. Now, waste heat to power is type of waste heat recovery system. Okay. So the idea is we are using waste heat from one system and then we are using that waste heat in power generation system. Right? So what's why we call it waste heat recovery. But there are constraints. If you're thinking about waste heat to power, we need to make sure whatever exhaust gases we have, those are clean and contamination-free. We also need to make sure waste heat is at a level on continuous and predictable basis. So there's continuous or predictable flow for waste heat source. That is very important.

And then if there are not other options, like, you know, if you are not able to reduce that waste heat, recycle waste heat, or recover waste heat, if all those options are not available, nothing is possible, then you should start thinking about waste heat to power. Because waste heat to power option is very expensive and a little bit complex – complicated. And then if you're going for waste heat to power option, try to avoid or reduce use of supplementary fuel. Because what happens is if your waste heat flow temperature, if it is fluctuating, what you try to do is you use supplementary fuel, maybe natural gas, to support your waste heat. And you use supplementary fuel to get continuous source of heat energy to generate power.

But you should generally try to avoid use of supplementary fuel because if supplementary fuel becomes expensive, then, certainly, your economies are wasted to power, becomes completely opposite. Okay? So you should avoid using supplementary fuel. So there are different waste heat to power options available today. And these options are available commercially. So steam rankine cycle, organic rankine cycle, ammonia water cycle, or super critical, CO_2 cycle. Right? All these different options are available, different products are available in the market. The problem is they're expensive.

As you can see, steam rakine cycle, our typical stem cycle regenerates steam using waste heat, and then you use steam to generate power. So, typically, it is $600.00 per kw. But if you look at organic rakine cycle, calina cycle, or _____ cycle, we'll already expense the option $2,500.00 per kw. So source temperature range working fluid, working fluid attributes, and then conversion efficiency. Those are, again, all that data is provided in this table.

So now let’s summarize waste heat management options. So recycling and recovery. So, number one, if you have waste heat, I think we should start with reduction option. Reducing waste heat is best option. Okay? Now, if you’re not able to reduce waste heat, then you should think about recycling and recovering waste heat. And so the recycling and recovery point of view, three possible options should be considered and evaluated for use of waste heat from a heating system.

So number one is use waste heat within the process or system, itself. This is the most economical and effective method of using waste heat. The second option is use waste heat within the plant boundary, itself. This option includes use in or for plant utilities, or using other processes. So this is actually a recovery part. Okay? So recycling or recovery. And then third option is waste heat to power conversion. But before you think about waste heat to power, start thinking about recycling option or recovery option.

Now, let’s go over process heating specific DOE tools and resources. So we have Better Building Solutions center website. On that website, we have resources like tools and resources for different energy support systems. So specifically for process heating, we have process heating tip sheets. And there are almost 11 pictures available: source book for indudsry, case studies, info cards, and pre-recorded webinars. We also have our two software tools. Two different versions of process heating tools. One is Excel version. We call it PHASTEx, and then second is MEASUR, our process heating assessment and survey tool.

So, again, on this website, Better Building Solutions website, we have almost 11 tip sheets on different process heating and energy efficiency opportunities. So, for example, preheated combustion air. Check burner air to fuel ratio. Oxygen-enriched combustion. So there are almost 11 different process heating opportunities related, tip sheets available on DOE website. And here’s an example. So if you look at – this is one example on the energy tip sheet on check burner to fuel ratios. And so there’s some description associated with this opportunity, and then we have available heat charge. And then here’s an example calculation on check burner to air fuel ratio.

So here’s one example. And then if you look at process heating resources website, again, this is Better Building Solutions Center website, again, we have a list of these top ten energy efficiency opportunities. Info cards, process heating info cards, source books, then technology assessments, and then the software tools. So we have manufacturing energy assessment software for utility reduction measure tool, and then processing heat assessment and survey tool. This is Excel version available on DOE website. And then we have also created dynamic manufacturing energy and survey tool. So those are resources are available on DOE website.

Now, the most important tool that is available on the DOE website is this MEASUR tool. Again, MEASUR stands for manufacturing energy assessment software for utility reduction. Typically, we use this MEASUR tool during our big plants and plant trainings. So within this MEASUR tool, you’ll see that there are two separate parts. One part is creating assessments, and the second part, we have properties and recruitment calculators.

So if you look at detail assessments for all our energy support systems, we have these energy assessment models. So for example from process heating, fans, steam. And also for energy _____, we have more detailed assessment modules. And so we're having to look at process heating more than today.

So if we look at process heating assessment module reading, the MEASUR tool, you will see there are multiple components associated with the software tool. So we have system assessment or system set-up, and then process heating assessment part, and then report section. And as I mentored previously, we have process heating calculators, too. And so process heating calculators, for example, we have these five very useful calculators. And then what you can do is you can just use any of these calculators, any of these different calculators and do quick calculations.

So for example, you can see the improvement calculator is about reducing oxygen level in exhaust gases, and then impact of that on thermal efficacy of a specific place. So these calculators are available. Okay? Now, detailed assessment point of view. We need to use these three specific components of process heating module. The first one is system set-up; the second one is process heating assessment, and the third one is report section. And within system set-up, what we do is we actually – we delve up baseline heat balance for a specific process heating recoupment.

And then once we have baseline heat balance, then using process heating assessment, we do a what if analysis on that specific equipment. So baseline heat balance and in modified conditions. And now modified conditions are this analysis part. We have two options. One is expert view option, and then second one is novice view. Under expert view, the idea is if you have baseline data and calculations for different heat losses for your specific process heating system, let's say, charge material, fuel gas, fixture wall, cooling loss, atmosphere loss, opening loss.

So if you have baseline numbers for specific process heating system, then what you can do is using expert view, you can modify a temperature, or dimensions, or oxygen level, and then you can do an what if analysis. So side-by-side comparison between baseline and modify conditions. And then that's how you do process heating assessment. And then you get results in report section. Now, novice view is much easier to use. So under novice view, the idea is if you have a baseline, how much heat you're losing to different losses.

So let's say flue gas, fixture wall, if you're losing a certain amount of heat energy, now, using novice view, what you can do is you can start indemnifying opportunities. So for example, preheat combustion air. Preheat charge material. So you select one of these opportunities. And once you select a specific opportunity, then the software tool will ask for modified condition data, and you enter that data, and then this software tool, it conducts side-by-side comparison between baseline and modified condition, and it gives you the same number.

So here is actually a screenshot of expert view within process heating assessment module. And as you can see, you have different calculators are part of your baseline. You have charge materials and flue gas, fixture wall, cooling, atmosphere, opening, leakage, extended surfaces and other losses. And the idea is when you click on wall, for example, you have baseline numbers. So whatever surface temperature, wind velocity, ambient temperature, _____, you are quantifying what heat loss. So you have baseline number.

And then what you do is your opportunity is a build wall insulation. And if you build wall insulation, your _____ temperature is going to drop, and then you're losing part of that on wall loss in MMBtus per hour. So you have baseline conditions, and then you have modified conditions. And then, here, we see results or we have help _____ your notes. The novice view idea is rather than side-by-side numbers like on baseline and modified condition numbers, here, what you do is user, select specific opportunities. And based on whatever selection or different approach, then we need to enter baseline modified temperature data, baseline and modify data numbers, and then you see the results on the righthand side.

Now, reheat furnace results, this is an example. What we did is we added data in process heating assessment module for a reheat furnace. And now it's showing us executive summary. And executive summary is actually showing energy intensity of that heat furnace, and your energy use, and your energy savings, and your cost, cost savings, implementation costs, and simple payback. And so if you look at first column, these are baseline numbers, and then all other columns, those are specific opportunities.

So for example, warm charging of slabs, improved cooling insulation, prepare wall insulation. So for different opportunities, you are going to see your energy intensity and energy saving numbers are changing. But last column is combined opportunities. Now, if we combine all of these opportunities, whatever compound effect on your furnace thermal efficiency, you see that in this last column. So what are percent savings if we combine all of these approaches? You're going to see 21 percent savings, and energy intensity is going to drop from 696 MMBtu per pound to almost 548 btu per pound. Okay? And the energy savings, cost savings payback. In the bottom, you see modified notes, and then this is your executive summary.

Now, reheat furnace results data. And the results data, what you see here are different losses. So charge material, that's useful. Useful purpose of heat energy, and then all of these are losses. And so baseline data, and then if you have different opportunities, under different opportunities, whatever changes to your different losses, you see those numbers in different columns. And then combined opportunities, you see combined in last column. This process heating assessment module also gives you buy charts, column charts, and then side-by-side comparison option.

And the best part of this process heating assessment module is the Sankey diagram. So this is baseline Sankey diagram for this reheat furnace example, and then this is combined opportunities. So what you can see is baseline gross heat input is roughly 278 MMBtu hour for this example heat furnace. But once you implement all these different opportunities, combined opportunities, you are going to see impact on gross heat input. Now, you just need 219 MMBtu per hour when we reduce all these different losses.

Now, as I mentioned, we use this MEASUR tool during DOE process heating in-plant trainings. During those in-plant trainings, we also use DOE's diagnostic equipment. So to a process heating point of view, flue gas analyzer in product gram, in product camera, those are important diagnostic equipment. And then so a combustion measurement point of view, if you use combustion analyzer, it actually gives you oxygen level, carbon monoxide level in exhaust gases, inlet temperature, flue gas temperature, and then it calculates combustion efficiency depending upon type of flue you're using in your furnace. Surface heat point of view, in product or product grants are very useful.

Just FYI, at DOE, we have this diagnostic equipment loan program. So if you decide to conduct process heating assessment yourself in your facility, and if you need to borrow DOE equipment, so what you can do is you can submit an application form to basically receive process heating diagnostic equipment from DOE. You can actually use those equipment for one day or up to four weeks. And this is free of charge, including shipping. Even shipping is covered by DOE. And the only thing is it's first come, first serve basis. Okay? So you can actually take advantage of DOE's diagnostic equipment loan program to conduct process heating assessments yourself.

With that, I would like to acknowledge a few experts and my colleague. Particularly, Dr. Thekdi, and then Glenn Cunningham. They are process heating experts. Greg Harrell and Riyaz Papar, they are steam experts. And then we have one of the staff members, and all these different individuals, they work together and then they build up major software tool, that DOE software tool we actually saw today. MEASUR. So all these people contributed in that software tool.

With that, I would like to take a few questions. We have a few more minutes. So I would like to definitely take some questions from our audience.

[Change in primary speaker]

Wonderful. Thank you so much, Sachin. Really great presentation, very through and in-depth. I appreciate you weaving in all of the ways to take advantage of the Better Plants and DOE program resources. We've received about eight questions so far. We have eight minutes. So I will stop talking and try to fire questions at you. Fire by all means. Certainly, if you have other questions, include them now or look through the questions and vote up or vote down the ones you want us to take because that will determine the order in which we take them. Sachin, let's take this first question here. How do you determine the proper full to air ratio. I'm not well-versed in steam systems. When I go visit facilities, they say their boiler rep turn the fuel-to-air ratio as part of their PMs, and I don't know how else to check it.

[Change back to primary speaker]
Right. Right. I'm almost feel like cross converting my own prestation here, but we couldn't of course. No, this is actually very important question. And, in fact, the next question also deals with fuel-to-air control. And it is very important. And, of course, in

_____ to furnaces, their needs are different. But, typically, if you're trying to dry something, melt something, or heat something, you don't need to really worry about – in many case, you don't need to worry about VOCs with any components in your surfaces. And if you don't need to deal with those, then ideal air _____ will control these. Basically close to stoichiometric ratio.

So what is stoichiometric ratio, right? Stoichiometric ratio idea is whatever you're trying to combust, whether natural gas, propane, or maybe blast furnace gas, _____ and gas. What you try to do is you try to provide perfect amount of air to basically combust that fuel completely. So that means whatever hydrocarbons you have, using oxygen in air, you're trying to convert everything to either _____ and carbon dioxide. So that is basically stoichiometric combustion. And generally what we do is we try to keep a little bit of excess air, so maybe two percent, three percent CN level in exhaust gases because we want to make sure everything is completely combusted.

Now, how you determine proper fuel-to-air ratio for your fuel? So depending on type of fuel you are using, amount of air needed is different. So natural gas or _____ and gas, completely different amount of air needed for complete combustion. And most important thing is you need to avoid less amount of air because if you have less amount of air, less amount of air than stoichiometric air, then you're going to see carbon monoxide your exhaust gases. And you definitely want to avoid that. And at the same time, you can have access air that necessary.

What happens then, one, oxygen level goes up and you will exhaust gases. So you're losing heat energy. So efficiency point of view is not good. But then at the same time, a tremendous amount of NOX is also generated. Because you are bringing in extreme NOX, external _____, along with excess air and so now you need to deal with excess NOX also. So, of course, a system-to-system is different. If you are dealing with VOCs, for example, _____, you generally try to keep 15-16 percent oxygen level in exhaust gases because you want to make sure you dilute exhaust gases to avoid detrimental impact of _____.

And then, of course, to control air-to-fuel ration, there are different mechanisms available. As I mentioned during my presentation, incinerators, cross connected ratio regulators, mechanically-linked control valves. Mechanically-linked control valves are very common. They give you _____ to one turn-down ratio. Most expensive system is, of course, pulsometer control. In that case, pulsometer control system, you are controlling both air and fuel of mass _____. And then you have actually better control, but it's generally really expensive.

[Change in primary speaker]

Great, Sachin, I'll give you the chance if there's a particular one that you're interested in now. I'm certainly interested – I like the question we're being pushed for carbon savings. Are there any viable or economic electric technologies available, but I recognize you may not be equipped to answer that one. So if there is any you're particularly interested in answering, I'm happy to defer to you, Sachin.

[Change back to primary speaker]

Okay. Okay. No, that is actually very important question, too. Electrification is actually a major pathway for decarbonization. And so replacing fuel-fired furnaces with electronic technologies, electric furnaces, definitely makes sense. The only problem is if your electricity is dirty, then you're not really making any significant difference because if you look at science-based projects or _____ emission projects, you include both scope one, scope two, and scope – in some cases, scope three.

So scope one and scope two emissions are included. And so it is very important. If you are going for electro technologies, it is very important that you have renewable low carbon electricity as your source. But, yes, there are definitely options available. Different fuel-fired furnaces. You have electro technologies available, and we can discuss that offline.

So this next one, how often should combustion system be tuned? Yes. Of course, it depend what kind of control system you have. Let's say you have mechanically-linked control valves. Typically, we see, again, on boilers, at least, minimum, you should do that two times in a year, in the summertime and wintertime because our gross temperatures are different, and so air densities are going to be different. And so at least minimum, if you actually tune your air filter using mechanically-linked control valves, it's going to be very important. Because what happens is mechanically-linked control valves, you are using two separate valves to bring fuel and air. Right? And you know two separate valves, and then two separate type of gases. You are dealing with two separate type of gases. Air and fuel. Right?

And so it is hard to match that valve profile, to perfectly match air flow and fuel flow, whatever graph you're going to see, that flow background is very difficult to match. So what you try to do is at least you match those profiles, like low file and high file models, and then you are generally in good shape. So one is two different system, and then at least low end, high-fired point of view, you should try two burners. Okay. Now, next one is how viable are condensing economizers in process heating furnaces?

[Change in to primary speaker]

Well, before you get into too many questions, I just want to give you a chance to promote the upcoming webinars and just keep an eye on the time. So maybe one more question and then move on to showcasing the upcoming webinars.

[Change back to primary speaker]
Right. Right. Okay. I think I have addressed most of those questions. Let's see. Last one is at what stack do recouperator make financial sense? We typically operate it around 350 digress Fahrenheit. So that one, system-to-system, furnace-to-furnace, and then type of

flue you're using, and fuel cost. You'll see different economies. One thing is within the MEASUR tool, we have a calculator that could actually help you do that analysis. By the way, one side-by-side comparison between, I just remember fuel best system and electro technology, if you want to cost comparisons side-by-side, we have, by the way, that calculator. We are planning to put it on the DOE website very soon. So contact us offline. We'll be able to share cost comparison calculator. Yeah.

All right. So I think that's it. We could actually could go for the next slide. Yes, thank you. So here. Better Plants online learning series there are different multiple upcoming webinars, specifically do not miss September 24 if you are interested in MEASUR tool. But all these webinars are going to cover important topics. Field validation is important. That's actually new initiative we're going to start as Eli mentioned. Energy management during a pandemic. And then process cooling. Those are upcoming webinars. And these webinars, by the way, definitely one and a half hours you're spending with us. But that's not it. Okay? After these webinars, please do not to contact us through our e-mails. Okay? Because even offline, we should be able to help you or learn from you. So with that, Eli, any last remarks from you?

[Change in primary speaker]

No, thank you Sachin. This was wonderful. I think that was an incredibly jam-packed full of information webinar today. You did an excellent job. If we didn't get to your question, by all means, you see Sachin's contact information and my information, or if you have any further questions, just shoot us some mail. We're happy to talk with you offline about this. And, yeah, thank you for attending today and we're looking forward to seeing you for next week's webinar. Thanks so much, everyone.

[End of audio]