Video Transcript

Webinar Title: Thermochemical Conversion technologies for biochar production aka Production of Biochar.

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Hello everyone and welcome to the Great Lakes Biochar Network's, second webinar here in the fall of 2021. This one is on the production of biochar. We're going to give it a few minutes as people trickle in, I see that number of participants going up right
now. If you wanted to introduce yourself in the chat, just your name and where you are, feel free to do that.
information, or if you're just here to learn more. That is wonderful also.
So again we're going to wait a few more minutes as more people come on to the webinar and we will get started in a few minutes.
Another person from Lansing Welcome again if you want to introduce yourself in the chat a little bit of housekeeping also is that we will be having a question and answer session.
This is the presentation by Dr. Christopher Saffron from MSU's Biosystems and Agricultural Engineering Department and the presentation is going to be about 45 minutes, and then at the end we will have the Q and A with him live and and other people from
the Great Lakes Biochar Network, unable to answer any of those questions. If your questions don't get answered, then we will certainly try to address them at a later date, but hopefully you will be able to talk about all of those that get presented
today.
So keep those coming throughout the presentation. They might even get answered in real time being typed into that q amp a forum, otherwise they will be answered by Dr Safran after the main part of the presentation.
It's great to see some people that are producing as well. Coming in there in the chat, you know, as also we go over things, one thing that will be interesting to hear is what other types of webinars and we're always open now is this newly formed network
where the network really is.
Everyone it's the core group that started at ms you but we want to be involving everyone so let us know what other types of webinars, you might want in the future and in terms of production.
We might even have a panel of producers on in the future as we look into 2022 and further of connecting people and everything else within the biochar bioeconomy here in the Great Lakes region, say a word about a close to 50 people right now. Please do keep introducing yourselves in the chat if you're just coming on.
But I am and I get started This is the Great Lakes Biochar Network, and we are talking today about the production of biochar, I am Dr Brooke Comer, I am the program coordinator for the Great Lakes Biochar Network.
So you are probably hearing any communications are going to be coming from me, and I am always here and open to all of the practitioners that are involved in biochar to get in touch with us and figure out how best will all be connecting, but the webinar
today is led by Dr. Chris Safran from MSC biosystems and agricultural engineering, and also a support from his graduate student PhD candidate, Rachel sack, also in biosystems and agricultural engineering,

and he is going to introduce himself a little
bit more again throughout the presentation, feel free to use the Q and A, and also the chat if you want to be talking to other participants also.
I will say, Oh, actually going back here I do want to say that our funders here are MSC project green. The Michigan Department of Natural Resources Division of forest resources, this was through a 2019 landscape scale restoration grant from the USDA for
service and support from MSC extension, and.
This, combined with all these webinars and just starting off here in 2021 is really the start of this network which originated here in Michigan State University, but it will be powered by and made up of people throughout the region.
And so we're here to help connect participants and stakeholders from all across the Great Lakes region, and even beyond, and that will really embody the network so the goal to serve the entire region and all interest regarding biochar.
Notice of non discrimination, the Michigan Department of Natural Resources ms you and the USDA we're all equal opportunity providers and are prohibited from discriminating on the basis of race, color, national origin, sex, or disability.
So, this is going to be recorded. Our goal is to provide the record of the webinar posted on the website which will be providing that link later. And also we will have an ad a compliant PDF of the slides.
In addition to any suggestions on how to make our offerings more inclusive and more accessible, please contact me with those suggestions.
And with that, I am going to send this over to Dr. Chris Safran.
And that will be starting now. Thank you so much for being here.
Welcome to the Great Lakes Biochar Network's presentation on biochar production technologies.
My name is Chris Saffron, I'm an Associate Professor in the Department of Biosystems and Agricultural Engineering.
I also have adjunct appointments and forestry and chemical engineering and material science, my colleague, Mrs Rachel sack is a PhD student, Department of biosystems and Eric cultural engineering.
And we're going to tell you about some of the reactor configurations that are used to make biochar.
And so the first question is, what is biochar? Biochar is a product made from the pyrolysis of biomass and biomass can take a number of different forms can be woody biomass, perhaps woody biomass growing plantations, can be forestry residues saw mill residues
agricultural residues like corn stover animal waste, like some of the dry maneuvers horse manure, for example, as well as aquatic biomass, perhaps macro allergies, the seaweeds after they've been dried.
And from there we heat those biomass forms in the absence of oxygen, and this is what's very important here. If we let in too much oxygen will combust all the biomass to co2 and water vapor, and we won't get very much biochar or very much bio oil, if
the liquid is what desire, the temperature range that we are most interested in, typically occurs between 307 hundred degrees Celsius, perhaps even more narrow range of 400 to 600 degrees Celsius is even more typical, and the products that we produce
include a solid, which we refer to as biochar a liquid which is now called bio oil, and a combustible gas, and we often combust that gas provides some of the drying heat, and some of the ignition key, it's needed to get pyrolysis reactions started will
use the words by which are and charts anonymously, in this particular presentation.
Charcoal can also be made from biochar and often is no charcoal typically has other additives,

sometimes including coal itself, and char coal. And sometimes, including binding agents like starch, and this is how char briquettes are held together often
is by adding some starch.
But we're talking about will be biochar where our and use applications will be such things as as soil amendments, or as sources of energy for heat our production.
So biochars made by a number of thermal chemical conversion technologies at the low temperature and is the technology known as tour faction, the chemistry of pyrolysis does start to occur during these temperatures range or faction you can see the top
figure on the left hand side under the word tour faction you can see slightly toasted would too heavily roast it would, depending on the tour faction severity in terms of time or reaction reaction time or temperature of reaction.
Below that figure is talented terrified biomass, sometimes referred to as char or biochar that telephone that teletype horrified biomass would be used to displace a solid fuel at home voting power plants.
As you move up this temperature range into the 400 to 600 degrees C range of temperatures. This is where the technologies of pyrolysis are employed, and they can be employed as either fast pyrolysis, which rapidly heats biomass in the absence of oxygen
or slow pyrolysis which much more slowly heats biomass in the absence of oxygen for much longer residents times past pyrolysis residence times are on the order of seconds or less, slow pyrolysis residence times can be minutes to hours today's.
And you can see the types of char products that we make.
If you focus on slow pyrolysis, which is the dominant focus of today's talk because the char yields are so high, during so pyrolysis.
We can do a number of things we can make briquettes like you see in the picture in the middle bottom right. Or, we can use the char as a soil amendment and use as a soil amendment we typically we may see things like yield enhancements of crops and so
here we show you a diagram picture of two plants growing one in soils include biochar and when it doesn't. And you can see the plant and the right has grown to higher yields.
So this is often what one wants to observe, when they men their soils with char.
You can also make biochar by gasification yes vacations goal is to produce gas, and then there's number of different things we can do with that gas, we can burn it directly for heat and power, or it can upgrade into liquid fuels using fishing trips synthesis.
It also co produces a small amount of char or biochar, and that small amount of char could also be used for various purposes. I'll point out that when you get to higher and higher temperatures, the possibility of making pie aromatic hydrocarbons and
some other organic contaminants does increase and so this is something to be wary of.
When it comes to using these gasification chars not always the case but sometimes it can be the case.
So focusing on pyrolysis. This begs the question, how it is pyrolysis occur. And the truth is the mechanism is very sophisticated pyrolysis reaction chemistries are quite complex there's a number of different reaction pathways there followed from the
carbohydrate polymers of biomass including sales and Hemi cellulose, as well as the LinkedIn component of biomass.
Fred chef is Ada proposed model some time ago, the late 70s early 80s that describes would pyrolysis, and he suggested that pyrolysis proceeds via three routes, one route to the char, which is our interest here today, another route to tar, which is now

named by oil, and a third route to combustible gases, and these combustible gases are sometimes coin non condensing gases. This is the gases leftover after you've condensed, the pyrolysis vapor two forms bio oil.
And then there are roots from the bio oil to the compressible gases into the char as well and so there are secondary routes that can produce more and more combustible vaults.
So, this mechanism was kind of useful because it helped us to try to untangle what might be happening during pyrolysis mechanistic way though today we've made rapid strides forward in our understanding of pyrolysis, we do have a ways to go.
We care about these sorts of mechanisms because if we know the kinetics, we know the rates at which reactions occur, we can use that information to better design our reactors.
Now we couple of these rate equations that we can formulate from the kinetic models with heat transfer rates and mass transport rates.
And so when we do that, we can better understand the entire physical, chemical process of pyrolysis.
So when you heat a thermal a thick particle. Perhaps if the radius of 20 millimeters or more like the serial particle you see on the left hand side of this slide.
As you heat it externally, you get an expanding layer of char that forms that surrounds a rapidly decreasing unreactive core of biomass as that biomass core reacts forms pyrolysis papers and more char, the pyrolysis vapors then have to transfer across
that Charlier in order to eventually vent out into the space in between these charged particles, that's the promises paper that we collect and can condense to make bio oil.
It's important that we understand these mechanisms, particularly the rates at which these vapors are going through this Charlier because embedded in that char layer, or the metals that the plant had transported from the soil.
And some of these metals are actually quite catalytic, and can catalyze, a number of other reactions that then proceed to form products that are collected in your pyrolysis paper, or they can catalyze the formation of chars.
And so understanding what's going on is really important, because now we can design better reactors, using that understanding, it helps us to de risk reactor design.
On the right hand side is a similar model only now the particle sizes been reduced 2.05 2.5 millimeters radius. And this particular model proposed by Jesse and Adele suggests that because of the transpiration tissue.
The vessel elements and trades and so forth that made up the conduits from routes through shoots to leaves for water flow.
Because of that, the directionality of that transpiration tissue. Be a formation of pyrolysis papers also proceeds unit directionally through these particles.
And so this is actually have someone interesting finding because now you can determine what the resonance time of these vapors happens to be inside these particles doing pyrolysis.
And this leads to one reason why you might elect to use fast pyrolysis versus slow pyrolysis, if your aim is to make liquids.
There's a smaller amount of time in which those cracking reactions, involving the metal catalysts embedded in the char is a very small amount of time that those cracking reactions can occur if you have very small particles.
And so, results like that are important because again they inform our ability to design better reactors.
Well, there's a lot of mathematics and a lot of chemistry that really accompanies this and it takes quite a

deep dive to really understand what's going on during the slow process process as well as the fast process process.
Now, it turns out it's actually quite easy to perform pyrolysis.
Here is an example of an earthen pit kiln.
And in an earthen pit kiln. You can see that we let air in on the,
on the far right hand side I'll point to it laser pointer air comes in. And this is a small amount of air. This isn't enough air to completely combust all the feedstock that we've buried in this earth and.
And what that does is it combust a small fraction that feedstock combustion is an extra thermite reaction so it generates heat, and that heat then is transferred to neighboring logs of wood to convert that material into biochar.
And so once these reactions of pyrolysis or ignited by combustion.
Then they are self sustaining.
And what happens is the vapors that are formed pass through and come out over here on the left, and are admitted into the atmosphere. I'll point out these earthen pit kilns are covered with soil.
Usually sandy, or lomey soil. And it's important to make sure that as this film operates the recognizing that the biochar volume reduces, it's important to fill in any cracks or fissures that form, because those cracks and fissures will allow fresh
air to infiltrate and cause combustion to occur.
And so, this isn't something that can be done for 20 to 30 days without monitoring, it does take frequent monitoring to make sure that anoxic conditions that are those are conditions in the absence of oxygen and accept conditions are are held.
This type of kiln system prefers a well drained soil, you certainly don't want a lot of water down here.
Okay, so that's important char yields are quite variable using this type of system from as low as 12 and a half 8% on biomass to as high as 38%.
There's really no automated temperature control here, and of concern that we'll talk about in a subsequent slide happens to be the emission of particulate matter, as well as volatile organic compounds.
And so if you're going to perform earthen pit kiln pyrolysis. Be aware that those emissions are occurring, and that if you have neighbors neighbors nearby there may be some nuisance odor complaints.
Okay, so if the soil is wet, or if it's just difficult to move it's difficult to dig into, you can essentially perform the same type of pyrolysis in a mound kiln.
And so this is just an above ground kiln, and we show you a depiction of that here in the mound kiln we typically leave a number of air inlets down below.
And those area and let's can be plugged once the pyrolysis is ignited and slow pyrolysis is occurring and char yields from these mound kilns tends to be in the two to 42% range.
This is actually quite a broad range.
But mound kilns are inexpensive to build.
Here's a mound kiln, where they've actually connected, multiple 55 gallon drums to serve as a chimney.
And so that's one way of lifting these emissions sort of off the ground.
And so perhaps nearby neighbors won't be exposed to any of the problematic molecules that you're emitting during pyrolysis. We'll talk more about those in a moment.
This particular mound kiln does have a condensate pipe to collect liquids, so liquids that condensed from the vapor can be collected there. And those liquids can be burned, as a source of heat or power if you have a hidden power generator.

You can also perform a slow process and a batch drum. This is a batch drum kiln. This is just a 55 gallon barrel. This system costs about $15 to make in this company, our HR HR has made thousands of these in, and sold them in the US and Kenya.

You can get temperatures around 500 degrees see you under low oxygen conditions and make by which are in this case for the purpose of its use as a soil amendment to improve crop yield

more sophisticated reactors have also been devised this is a multiple hearth kiln this particular film can operate at up to 2.75 tons per hour, and the feed comes in up at the top, and it goes into the first Trey, you see here.

And these are what are called rebel arms. These rebel arms are connected to a center chef which rotates. And as the central shaft rotates the rebel arms, push the biochar towards holes in these trays, allowing the biochar that's forming biomass and

top on the top tray, but eventually by charging it to lower trays pushes that solid material to a lower tray. And this material, your feast deck is successfully pushed to lower and lower trays exposed to temperatures of pyrolysis process occurs and by

time you get to the bottom, you can collect your biochar product listed here is charcoal. Okay, but it would be biochar start with biomass going into this multiple hearth count and a counter current direction, we let in some air.

And so this air then combust a fraction of the biochar is that combustion that generates the hot gas that raises the temperature into the four to 600 degrees C temperature regime that causes the pyrolysis to occur.

And you can see here we can collect the particulate emissions.

Collect the volatile organic compounds that come off. And in a system like this we could design a, an appropriate flare, such that we convert those carbonaceous emissions into co2 and water.

You could also splice in between the flare different types of pollution abatement equipment to minimize emissions.

This is called a multiple hearth kiln.

Cornell has devised a reactor a continuous reactor. And in this continuous reactor is of the drum kiln variety.

This particular reactor exists, and one of their pilot facilities, it can.

Except, up to 50 kilograms per hour of throughput.

There are five adjustable heating zones and can you can achieve temperatures up to about 600 degrees. See, there's a variable in feed agitator.

And that agitator is connected to a number of paddles, and those paddles push the biomass through the barrel.

You can control residence time with the variable speed drive on that.

And that's series of rotating paddles, you can also increase or decrease the inclination angle of the, of the drum count, which also assists in controlling and adjusting residence time, so they can control residence times between a low have nine minutes

to 45 minutes. In this particular drum count so there's some control of residence time, which is one of the key operating variables, and there's control of the temperature and other key operating variable, as well as the feedstock flow rate.

So these types of reactors are highly instrumented highly controlled.

And because of that you can achieve biochars with more desirable properties and you might otherwise be able to.

There are so fast pyrolysis technologies and I just share with you to the one on the left is a fluid ice bed reactor, and in this fluid ice bed reactor, the biomass is metered into a sand bed which is fluid iced by hot gas from underneath, and the hot
gas and parts of force on the sand particles that are in this fluid ice bed that counteracts exactly the force of gravity in the opposite direction. And so the sun doesn't move, but it is gently fluid is which allows you to push the biomass into the bottom
bottom side of the reactor.
The Sam serves as a Heat Transfer Medium rapidly transferring heat to biomass, the order of perhaps 1000 degrees Celsius per second. And what happens is you create pyrolysis paper and biochar.
go into a cyclone where the char pyrolysis papers are separated from one another, the pyrolysis vapors and then condensed to form bio oil which is the liquid fuel intermediate to hydrocarbon fuels, and then by which are you typically don't get the same
yields of biochar with fast pyrolysis as you do slow pyrolysis on the order of 15 to 28% are fast pyrolysis whereas you can get 35 to 48% biochar yields a slow pyrolysis.
Nevertheless, and if liquid fuels are needed, and if liquid fuel economics from fast processes systems can be supported by Oh chars could be produced in relative abundance because of the magnitude of the demand for liquid fuels.
The reactor and the right is a research building fluid is bad. And I just want to point out a number of the fast pyrolysis reactors, don't actually produce biochar.
They don't export biochar they produce it, but they don't export it. And so what that means is the char comes out with the sand, which in the case of a recent circulating fluid ice bed comes overhead with the guests and char.
And then the char and sand go to HR combustion unit where the char is combusted in the presence of the sand to reheat sand. The sand is augured back into the reactor.
And so char doesn't get exported from the battery limits of the pyrolysis facility.
We have at Michigan State is something in between fast and slow pyrolysis I residence times on the order of 20 to 30 seconds. This is a screw conveyor pyrolysis reactor.
And up here at four is our feed hopper and the biomass goes into our feed hopper and then down into the reactor barrel. We have three heating zones here, and we can control our temperatures up to about 550 degrees Celsius.
and what comes out of the reactor is biochar and pyrolysis paper. We don't use sand as a Heat Transfer Medium, instead we use the externally heated wall of our reactor, as a source of heat transfer the vapors are then condensed through to condense answers
and recognizing that even after condensation we have aerosols in our gas stream. We run the stream through and electrostatic precipitate or which strips remaining aerosols.
And from there, the gases come out and go into a flame calorie matter where they heat water, a known quantity of water, and then we can record the temperature rise to calculate how much energy, the gas stream has recognizing that we want to use that guests
stream as a source of heat to heat a reactor.
And here's a picture of that reactor setup. And so you can see the the feed hopper here on the left, the reactor bear on the bottom. These are, this is the char trap.
And the two condenser, We collect our bio oils and balms mason jars.
This gas and goes overhead to a electrostatic precipitate or and below this electrostatic facilitators another ball mason jar, this gas then goes over into a flame calor matter and we can measure the energy

content with that device.
Looking down the biochar trap, we take the top off, you can see it we collect biochar there. And we typically get yields as low as 12 8%. And as high as 25% in this particular device.
And they that condensed gas is combustible as you can see here.
So just in review.
Starting with tour faction This is the low temperature version of pyrolysis. We do get that relatively high solid content that materials is really for displacing coal and coal fired power plants.
Though you get a high solids yield. There's still a lot of unreactive biomass into horrified biomass that terrify biomass product that you produce, and that unreactive biomass would include things like carbohydrate polymers silos and Hemi cellulose and
and so often, we don't consider terrified biomass as a source of biochar for soils, instead we look too fast pyrolysis and slow pyrolysis for doing that.
Best Practices biochar our yields are about 15% or so slow pyrolysis by higher yields are about 35 weeks center so yes you can derive biomass from gasification New Order of 10%, but we just have to be a little careful as to what sorts of organic contaminants
that by which are might contain because of the high reaction temperatures we exposed that solid material too.
There are a number of biotech applications that we need to be aware of that go beyond its agriculture use of course heat and power is one use we could burn biochar make heat and power.
There are a number of future uses and evolve the building sector.
And this owes to biochar's low thermal conductivity slow flammability is high stability.
We can use by Charles the catalysts we use it as an electro catalyst and some of the electric analysis work we do to upgrade pyrolysis by oils.
There is some evidence that it serves to replace sulfuric acid and biodiesel production animal feed additives, as another area of application. There's evidence of increased gut health increase speed efficiency toxin absorption, as well as decrease methane
release, very important for the cattle industry.
There are human healthcare applications that can be expanded upon with biochars, and then some more unique applications like sodium ion battery production, where a Morpheus carbons are needed or the production of super capacitors and there's lots of
directions biochar is going with regard to end uses for it. A number of folks have have wondered about different activation techniques classically biochar is activated, most often by steam, where the steam is usually high pressure high temperature steam.
And what this serves to do, typically is to increase the surface area of these biochars to make activated biochars or activated carbon and having activated carbon is important because it will increase the absorption and removal of such contaminants
as heavy metals or, or dies or oils from water streams or from air streams, very important for wastewater treatment.
So, classical activated Asian classical activation involves, perhaps steam or other gases like carbon dioxide can be used as an activating agent as well.
And there are a number of other methods, physical methods use for activating biochars.
It's not just about increasing surface area, however, changing the functional groups on the surface of biochar can also be desired.
For example, you might elect to increase the cat and exchange capacity by oxidizing the surface of

biochar using hydrogen peroxide, in which case you're using a chemical activation approach, and there are a plethora of chemical activation approaches
and involve acids and bases, and so forth, where the goal is to change the types of functional groups to add functional groups to subtract functional groups from the surface of biochar, and lots of and uses for these sorts of things from electro chemical
energy storage to pesticide removal.
It can improve biochars the soil amendment, for example if you increase the Kenyan exchange capacity. There are biological activation mathematic mechanisms used as well composting as an example. We just mix the biochar into a compost pile for weeks to months.
And what you end up with is a biochar that can improve soil structure, soil properties you get some increased water availability, some evidence of increase of decreasing nitric oxide and methane emissions from field applications.
And so there are biological activation methods that are of interest to those of us in this field as well.
So, even from the same feedstock biochars produced under different operating conditions will be different.
And so here's a study by brunette l published in soil biology, biochemistry using which draws a feedstock, and they examine for treatments, a soil control where they didn't add biochar.
And then a treatment that adds slow pyrolysis by which are at five 8% in soil. Another treatment that adds fast pyrolysis by a char 5% in soil, and then a final treatment that just takes raw untreated wheat straw and adds it in five to 8% concentrations
in the soil.
And so the sole pyrolysis biochar was produced under different conditions and the fast process by which are the heating rate was much slower at six degrees Celsius per minute versus 250 to 1000 degrees Celsius per second, and the heating time was two
hours for slow pyrolysis versus less than three seconds for past pyrolysis. And so then they went through and they looked at some of the properties of these different biochars and compared them.
And so looking at the carbon content. You can see the slow pyrolysis by which our has about a 78% carbon content, whereas the fast process by which hours at 49% only slightly higher than the untreated straw.
The action contents are also very different. The slow pyrolysis action content is about 7% and fast process action contents 24%. Both substantially lower than the 44% oxygen content of the original straw, which draw the ash fractions are about 20% for
slow processes and almost 22% per fast process so they're not too different, but they are quite different from the original wheat straw. And that's because the biochar concentrates the inorganic component inorganic fraction of which straw into itself,
the organics typically aren't volatile so during pyrolysis, they just become a fraction of the biochar
sales and Hemi cellulose does remain, there's a small amount of these carbohydrate polymers present in the fast process by which are but none of them present in the slow pyrolysis by which are the pH is are different, the pH of a slow process by which
our is relatively high at 10.1, and about neutral for fast process is 6.8.
And interestingly the surface areas aren't that high. We tend to think of Charles biochar is having high surface area, but these surfaces are actually quite low from both of these two processes.
The surface area so they're quite a bit lower than which are pyrolysis, particularly as those are around 100 meter squared program and so something's different about wheat straw then would be a biochars

made from woods, now employs steam activation
one of the physical processes we talked about, you can greatly increased these values.
Well, this difference in properties has some ramifications. This experiment was conducted observed that there was a co2 pulse from the different soils that were collected during the first 10 days of a 65 day trial.
And the pulse was found to be greatest if you just land applied the wheat straw, the wheat straw was very accessible. Very label to the micro organisms in the soil.
And so you've got a large co2 pulses a result, the slow process pulse did occur but it was very small. And the authors attributed this perhaps to some absorbed co2 on the surface of the biochar owing to its high pH basis are capable of trapping acid
co2 is an acid when it's dissolved in water forms carbonic acid.
And so perhaps some of that co2 is trapped on the surface and was just liberated over the course of the first 10 days.
Best promise this pulse was greater than the slow pyrolysis pulse, and they attributed this to the fact that the fast pyrolysis had a larger content of these carbohydrate palomas which micro organisms, perhaps were able to access quite easily.
And of course the microbial mineralization rate from we struggle was, was quite large. Well this slide just serves to impress upon you that biochars even from the same feedstock have different properties, when land applied and that or at least in part
part to the physical, chemical properties so the biochars, as made by these different processes.
Here emissions are important to discuss.
Recognize that fast pyrolysis air emissions will be different than slow pyrolysis emissions. There are lots of organic constituents, and both slow and fast process emissions I will say that the slow pyrolysis papers tend to have higher contents of carbon
dioxide, carbon monoxide and carbon dioxide. So just considering the slow pyrolysis air emissions in an uncontrolled bash reactor, you can see the emissions in terms of carbon monoxide in terms of methane, in terms of non methane hydrocarbons, and total
suspended solids are greater than if you work with a controlled continuous reactor, the controlled continuous reactor emissions are quite a bit lower.
So your ability to control those emissions goes up with increasing automation, that's something to consider when it comes to regulating emissions and considering whether to practice at small scales or large scales.
energy analysis of pyrolysis is also interesting if we take corn stover which is the leftover stock and leaves the corn plant after grain harvesting, and we take one metric ton and we push it through this process of drying and pyrolysis. You can see of
the 16,000 mega joules that goes in, more than half comes out is biochar under slope pyrolysis conditions, and the rest goes with the vapor stream which this group is elected to oxidize thermal a bust to generate a hot gas, which is then run through a
heat exchanger to transfer the heat and deliver it to heat applications, which include to some extent the processes of drying and pyrolysis, themselves, you can see these recycled heat lines here.
Note the amount of process he needed for pyrolysis is not that great. You have to add some energy to raise the temperature, the specific energy needed to raise the temperature to the, the ignition temperature process but once it gets started.
It's fairly self sustaining so it's not very energy intensive to run, what they learned in this study was that

dry feeds, like poultry manure horse manure, or dry cattlemen yours are actually reasonable feedstocks for this type of system but wet foods
like dairy manure aren't net because of the need to boil water off the web deed prior to performing pyrolysis.
They also learned that yard waste was a very economically favorable feedstock because you can charge a tipping fee.
And they learned that a carbon credits are important. When they got to carbon credits of amounting to $80 per ton of co2 equivalent that led economic feasibility.
And they also found that the economics were favored for decentralised distributed systems, smaller systems, perhaps cooperatives farmer forced cooperatives, where the systems are located near to the feedstock.
So the hauling costs are minimized,
different researchers have looked at centralized facilities. This is an example of a large centralized facility, processing 2000 tons per day of dry corn stover, and they used slow pyrolysis at 400 degrees Celsius and one atmosphere to achieve an internal
rate of return of 10% to get that inventory of 10% they needed a biochar selling price of $346 per metric ton, you'll see in a subsequent slide that selling price of biochars very important as $60 per metric tons of co2 equivalent this equates to about
$110 per ton of biochar, so that gives you an idea as to what carbon credit, and what additional value by HR has to have in order for it to be accessible on the market.
And they have performed this sensitivity analysis and recognize that biochar yield is a very sensitive parameter. And here you can see that if you increase the biochar yield from 36%, which corresponds to their 10% IRR down the center line, you increase
that the 45% there I our approach is 20%.
If the biomass cost is decreased to $55 a ton from $83 a ton, then they also start to approach 20% IRR.
If you can get a gas credit from the CO produce combustible gas.
You can get ours of 20 20% fixed capital investment, if it's lower from 113 million dollars to $79 million.
This also increases your IRR and so you can see from this tornado sensitivity plot, what variables most sensitively impact profitability.
And what we learned is that IR must be high to attract attract bank invest in 10% might not be enough to that.
Another study came along and looked at by which are price selling price. And so they surveyed by which are selling prices back in 2013, and they learned from that survey that the prices range from $80 to $13,480 per metric on.
This is a very wide range of prices, at least in part, it goes to biochar properties, the properties are different and so the prices the value of the materials different.
And what this group did is they looked at four scenarios, using two different reactors schemes scenarios, A, B and C all use an auger reactor and scenario D used a hearth kiln reactor scenario, a co produced by a char and liquid fields, but didn't
include ring credits.
And so by not including green credits you can see their net present value is tends to be below zero.
Right.
So these distributions that are plotted here are plotted by performing a Monte Carlo simulation, where they did 10,000 iterations, with varied parameter sets, where each parameter was very within its own

distribution function.
And so upon going through all those iterations they were then able to determine the distribution of net present values that could be achieved for each of these scenarios, because scenario A's me net present value is negative, more likely than not, this
auger production technology using Riggins wouldn't be feasible, under the conditions of fuel prices and post in 2018, we had low fuel prices in 2018.
You go to figure be, you can see with auger production, including a rain credit. This shifts the distribution over where the Nene distributions now right at about a net present value of zero.
If you only produce biochar and auger. Okay, without a ring credit because you're not selling liquid fuel anymore.
The distribution is just back to the left, more negative.
And this is because the auger reactors are capital expensive.
If you come back to the hearth kiln reactor, which is less expensive to construct and implement reactor, so claim the authors, then this distribution shifts to the right.
And so you can see here in panel D with the hearth kiln more likely than not you can make profit from such implementation. Again, this is for the economic conditions back in 2018 which we don't have today in 2021 fuel prices are much higher today.
So, this these results I wouldn't take is axiomatic, but what I would take from this is the range of of biochar prices quite large and the range that which other variables, play in the system are also quite large, and that contributes to a range of expected
profitability. net present values in this case. And so this type of analysis is really what's needed to understand the likelihood of a given venture being profitable or not.
With this group learned at the end was that though we've been focusing on increasing the biochar our yield from these reactors and decreasing feeds costs.
The biochar are selling price is the most sensitive variable. And so we really have to better understand what goes into biochar are selling prices.
So on this slide, we look at the x and the environmental impacts This is the life cycle assessment slide. And I just have copied here sensitivity analysis from paper published at Argonne National Laboratories, some years ago, notes, what's not on this
this figure, are the two most sensitive parameters. They are biochar yield and carbon content, they are so sensitive that the other parameters appear insensitive and comparison, so they were taken off the char.
At the top of this char.
We have the soil organic carbon change. And if we increase the soil organic carbon.
2.14 tons per Hector.
That's the change we increase it by point one four tons per Hector, we can decrease the greenhouse gas emissions by over four grams of co2 equivalents per megajoule.
Okay, that's kind of interesting.
This group looked at biochar application rate.
And an interesting thing that they found in the literature was that there are potentially positive priming effects of applying biochar to soils and so if you add a biochar to the soil, you might actually positively prime micro organisms to degrade neighboring
or accessible soil organic carbon.
And so adding biochar might not necessarily be a good thing in all cases, they took a worst case scenario

to this, and subjected this to a worst case scenario evaluation.
And so, if you apply a large amount of biochar of the soil they found that there was some evidence of positive priming that could result in increased emissions, but probably not that much.
That's what this blue bar here shows you, if you vary the carbon stability factor which has to do with how stable the biochar carbon is point eight is the base case value at zero if you increase that 2.9 meeting 90% or so the biochar carbon is stable.
Then what happens is you decrease the amount of the missions. As a result, and so they also looked at nitric oxide emissions reductions if you can get a 20% nitrogen oxide emission reduction.
That also serves to decrease net greenhouse gas emissions. So, this type of sensitivity analysis is important for understanding what most evidently affects the life cycle greenhouse gas emissions response.
When it comes to biochar application so these types of sensitivity analysis are important to perform. It gives you an idea as to what the most sensitive parameters are and what we should be most careful of when we, when we implement these sorts of technologies.
That is land to find biochar.
So we've learned a number of things, just in summary, biochar conserve as a solid field soil amendment, a high surface series orbit and, and many other end uses many soil slow pyrolysis configurations exists from high tech low tech from high to low cost
least production techniques that avoid air emissions and suspended particulate should be developed and encouraged and biomass fast process with biochar and application can potentially produce carbon negative hydrocarbon fuels we've learned this from
my research at Michigan State. And so if we use fast pyrolysis wisely and upgrade the result and bio oil appropriately. We can devise systems that can produce liquid fuel in a way that actually net sequester co2.
And so I just end with this picture of biochar taken by our own Dr. Jessica myself and her laboratory and you can see it's very porous nature. For this reason you'd expected have high surface area.
And so lots of applications are dependent on on high surface area.
With that, I welcome any questions. Thank you for attending.
Great if there are any questions.
shins. I think we can take them.
Looks like there's some questions in the chat that are popping up.
Should I start from the top broke the Do you think or would it be best to start at the bottom here, whatever way you would like to take them there's also one there that's in the questions and answer forum also.
Okay, great. Well thanks for pointing that out so we'll start at the top. And so it says here, any data on using biochar and Lake shores.
So, I suspect what you're suggesting is maybe these applications where you see putting biochar in the sleeves or socks. And then using the biochar packs in such a way to treat nutrients, or unwanted metals and I along shorelines that I've heard of I've
heard of doing that with rivers that are contaminated for example with things like p pass. And so there's precedent for those sorts of applications and that's where the question is headed.
If you're talking something else like just blending the biochar to the lake shore itself I don't know that I'm aware of that maybe one of the social scientists would be able to pick up with that one, or added something after that this was in an attempt

to filter stormwater runoff. Oh, yes, there we go. So that's, that's what it would be. Yes. And so you could you could certainly do that sort of thing.
I point out that not all biochars are created equally and I hope to portray that in the presentation. Some have I surface areas some biochars have low surface areas, some have a high cat and exchange capacity, some don't.
And so, one has to understand the physical or at least have measured the physical, chemical properties of your biochar before before applying them biochar are certainly not just one thing, it depends on the feedstock it depends on where the feedstock
was grown it depends on the way the feedstock was processed. So those all those sort of steps in production and biochar from its cradle that is the photosynthesis conducted by the plant in whatever environment that plant was growing all the way to its
production is biochar all those steps matter.
So, Okay, so that's the first question. Anything to follow up there, it looks like that's pretty good.
In the Q and A.
And so, then go to the Q and A next. I do have one question here asking me to define Rennes and IRR I apologize for not doing that I must have missed that those acronyms, you know some acronyms, when you're so familiar with them you forget that they actually
do in fact need identification.
RIN is a renewable identification number, and this is a program that is established by the ugliness the US EPA and allows one to collect credits for producing biofuels.
And then IRR is a profitability metric it's known as the internal rate of return, and the internal return I know is often called the discounted cash flow rate of return as well.
It's a profit profitability metric that accounts for the time value of money. And so it's a little bit more robust as a metric than something simple like the return on investment return on investment just an algebraic relationship, where's IR is a little
bit more robust and it accounts for monies changing values time value.
And so just kind of scrolling through these there.
There was one on the Kon Tiki kiln, I believe that was queued up by Brooke Did anyone have a question there, it comes up in the Q and A question in there for you.
Oh, so it's moved over there. Okay. Oh, some pros and cons of the Kon Tiki kiln. Okay.
And so the the county county is another of these what I would call relatively low tech biotech or production production kiln.
It would be in the same family as the batch drum kiln that we showed you, but the Kon Tiki kiln is actually open to the atmosphere.
And so, you put your biomass inside of it and then the biomass on the top is what sort of sacrifice to combustion. And is that combustion takes place.
And in so doing it spreads the flame across the surface of the kiln. And that serves to actually combust volatile organic carbons and and particulate matter that are being it's being emitted as the pyrolysis and the combustion is proceeding and so if
you can get complete combustion, ideally you would only emit co2 and water vapor.
And so in that way. Such kilns would be a cleaner way of making biochar cleaner in the sense that the error missions would be reduced.
I'll point out that it's it's highly unlikely their missions are eliminated. It is after all open to the environment. And so, you know, the efficiency of the combustion of those admissions really matters

emissions that escape are going to be emissions
that one has to account for. That being said, there are certainly lower tech technologies that don't do nearly as good of a job as the Kon Tiki kilns apparently do.
And so that that would be an advantage, along with its simplicity and it's it's low cost.
And if you go to the web, you'll see these are actually quite easy to cool off if you haven't xxs to a water source, just add water and then when done you can just dump everything out quite readily.
The advantage there versus earthen pit kilns is with the earthen pit kiln you gotta remove that, that, that soil layer that you put on top as a cap recognize some of that is going to be hard to separate from your char that you've produced underneath
and you got to go digging after that char pull it out of that, that Earthen pit. And so those are some I think relatively straightforward advantages and maybe one disadvantage.
The disadvantage again with the air missions and and to an extent the yield as well. When compared to the more sophisticated instrumented kilns, like the multiple hearth kiln or like the, the rotating drum kilns, or the paddle Qian that we showed you
Cornell has those sorts of kilns, you're going to have you'll have really tight temperature control. You're also going to be able to have very tight residence time control. And so the severity of pyrolysis can be very well controlled with the, with
And so the severity of pyrolysis can be very well controlled with the, with the more instrumented kiln this you're looking at a small scale, the kon-tiki is an excellent.
If you're not looking for big equipment investment. It's definitely miles, better than any kind of kiln situation Earth and set up that you could do in a barrel.
Because of that flame curtain that's going on and if you're in a country that also needs heat for food production.
Then you're going to take that to another level of potential there.
And also say Chris in your discussion of some of those emissions that also relates into a question here by David Newman from the Michigan DNR asking about particular emissions from the continuous production systems that are available today, and I will
say just real quick before you answer, we are coming up to three o'clock.
Recognizing that some people might need to be coming off anything that's not answered in our follow up email to today's webinar will also have a link to the recording, we can answer some of these additional questions, especially those that aren't so much
production related. I see about water retention and and using them in conjunction with mycorrhizal fungi, all very wonderful topics that we can certainly address all of these, I just want to say that, with it being three o'clock if we don't get to all
of these they might also be in topics for future webinars for the Great Lakes Biochar Network.
So Chris if you want to say just a little bit more about those emissions and any closing remarks and we will get all of those other things answered in another way through our website and a follow up email on this webinar.
Yeah, absolutely, emissions are very important here. And I wish there were a singular answer but since there's such a variety of technologies, such a variety of feedstocks, you're going to see a lot of variability with regard to emissions of the constituents
that are emitted their amounts that are emitted.
There's going to be variability, you have to account for the, the high more highly instrumented reactors, this is to David Newman's question them DNR, the more highly instrumented reactors.

It's actually quite a bit easier to implement downstream pollution abatement equipment, right to achieve endpoint emissions that might be desired. That's the advantage of systems that maybe are more medium to large scale is the those technologies become
maybe more available and more affordable at the smaller scale, you know, even with the Kon Tiki kiln. You're going to have some error missions, it's not going to be a missions free.
So how does it compare as a frame of reference, how does it compare to an outdoor wood stove or wood fired commercial boiler system. Oh, wow. Well it depends on which kiln your you're making that comparison to, you know, these Earthen pit kilns or
or the mound kiln, for example, there's quite a bit of a mission there. Okay.
The Kon Tiki kiln those emissions are cut down substantially.
But they're, you know they're not zero.
So I don't have I don't have numbers that I can compare directly to an outdoor wood stove, recognizing that even outdoor wood stoves have quite a bit of variability.
And again, we can also maybe try to get some more information on those and get some more specifics, some of those questions about the particulates and everything could go into some of those frequently asked questions that should be coming up on our website.
So unfortunately with the time that we are at we could maybe stay on and answer a couple more questions but I wanted to share my screen again just for a second that here we are with our future webinars, so much of what Dr Safra talked about does lead
into the economics of biochar production and use and so hopefully you are available on December 9 at 2pm. Eastern Time. Also to be held here as a zoom webinar, if you are not already registered, you can go to the link on our websites and that will be
coming up, and so much more of this will then be discussed in that presentation, and as I said, we can try to answer the rest of these questions through, through our website and our follow up email.
So thank you all for coming. If anyone would like to stay on if you were able to stay Chris, and that is great but otherwise. We just want to say thank you from the Great Lakes Biochar Network and again, thanks to our sponsors project green, the Department
of Natural Resources, the US Forest Service Department of Agriculture and Ms you extension.
So whoever wants to still stay on with the chat or the questions, otherwise we are going to just keep all of these questions and chat recorded in order to address these further so thank you so much for coming, Chris you have any other last comments.
Um, I think that this technology has a lot of potential. It certainly has a lot of potential to help abate climate change and.
And there's a lot of other uses of biochar that we're just now exploring so hopefully this can be a launchpad for looking at those potential reality.
So, thank you.
Thank you all for coming, and we will hopefully see you at the next one and keep any suggestions for future events coming to me, glbn@msu.edu. Thanks again.