>> Grace Weber: Alright, let's go ahead and get started. Hello and welcome to our Corrosion Webinar Series. My name is Grace Weber and I will be hosting today's webinar. We are with the Materials and Corrosion Laboratory. which is part of the Bureau of Reclamation Technical Service Center, located in Denver. We put on four corrosion webinars per year to share topics in our four main disciplines: cathodic protection, protective coatings, geosynthetics, and hazardous materials. Today we'll be focusing on our current research involving cavitation resistant materials. But first, a couple of housekeeping items. We are hosting today's Corrosion Webinar through Microsoft Teams Live Events and we will be recording the presentation. If you would not like to be part of the live recording, please leave at this time. And the recording will be available for viewing after the webinar is over through the same attendance link you received in your email. There is also a live Q&A chat feature. So, please submit your questions as you think of them during the presentation. To access this feature, you can click on the Q&A icon, which looks like a chat bubble with a question mark inside. We will be monitoring the questions and hold a Q&A session at the end. With that, I would like to welcome our presenter for today, Dr. Chrissy Henderson. Dr. Chrissy Henderson has a Ph.D. in Engineering from the University of Denver, a professional engineering license, and seven years of experience at Reclamation as a researcher and project manager on cathodic protection, materials, cavitation, and other related projects. Dr. Henderson is also a flying trapeze artist in her free time, and she has performed in a number of trapeze circus shows in both Colorado and Arizona. And now I will hand this presentation over to Chrissy.

>> Dr. Henderson: Thank you so very much for the introduction, Grace. And I want to welcome all of you to our webinar today. As you can see on the screen, Dr. Allen Skaja is also a co-PI in this research that we've been doing. And we were both planning on presenting to you today, but he is out on inspection this week, so I will present for the both of us. Dr. Skaja is one of our protective coatings specialists. And you are free to contact either one of us after the webinar if you have any questions or ideas or funding opportunities. Or maybe if you would even just like us to look at a material option. We would be happy to communicate with you by email. I'd like to go ahead and start with a cavitation overview. So essentially, cavitation is a rapid formation-- and rapid is the keyword here. It's a rapid formation and collapse of vapor bubbles in water with a sudden pressure change. This could happen in water that's accelerated to high velocities. It could also happen where there are big rapid bends in the water directions. Sometimes we see that with some of our pipelines when there is a sharp bend. And essentially, I'll kind of outline it here in three steps. And what we see for step A is, essentially, the pressure of your liquid-- or in our case, water-- will drop to its vapor pressure. So in the liquid you'll get these bubbles of vapor pockets. You could also call them voids if you like. And essentially as they form, they expand because the pressure is really low at that area. And then if you move to Step B-- and you can follow steps A, B, and C in the diagram at the bottom left. But essentially, as you move to an area of higher pressure... The pressure pushes against the bubbles and they start to self-implode and suddenly collapse. And this releases high energy shockwaves which do a lot of damage. So I do want to point out that it is very rapid. This process happens very quickly. And what you'll see in the picture on the top right is a high speed photography... image set that was taken, showing the cavitation bubbles in their expanded form and then collapsing as the pressure is increased. So essentially, as this process is happening, you will have microscopic impacts That will erode the structural surface of your structure that this is occurring in. The microfractures happen on the surface and they begin to build up and get worse. This also creates giant-- can create pits, holes... And then you get a material failure through fatigue or other phenomenon. And here, what I'm showing is an image of the Glen Canyon Dam spillway damage that happened in 1983. The picture on the right shows the spillway tunnel with big cavitation gouges and holes that has happened to the tunnel. And just to give you a perspective of how big these holes are, you can look at the image on the left. And you can see how the gouging has happened. It's gone through the concrete and then it goes into the soil underneath. And just erodes it away. Another example of this kind of spillway tunnel damage would be the cavitation damage that was experienced at Yellowtail Dam. Keep in mind that these holes are deep gouged out areas. And you can actually see in this image it's not as big as the Glen Canyon one. But in this image you can see the person that's actually standing next to the wall of one of those pits and holes and gouged out areas. Those are a pretty significant size. I showed you some concrete spillway structures with cavitation damage. Here I'm going to go ahead and start showing you examples of metallic structures where we commonly see damage. These are not the only structures we see the damage in, but these are the ones we're going to focus on today. First one that is pretty prevalent for us and for the hydropower industry is the turbine runners. These are essentially-- The turbine runners are essentially the spinning part that has the water exerted on the blades. And it's converting the water's kinetic energy into a rotational force and converting that into the power that we use. What you can see that's important about this picture on the top right is these rust spots. They look like... elongated semi-circular type rust areas. And what has happened here is that generally when we do turbine runner repairs, we'll have a stainless steel base material, and then we might do a weld overlay-- a stainless steel weld overlay-- on the top of it. Well the two materials are different enough that they actually create a galvanic corrosion cell between the two. Anytime you have different metals, you can get a galvanic interaction. But you don't see this until it gets weak enough that the cavitation pulls those off-- the repairs off. And then you can actually see the evidence of the galvanic corrosion that had happened between the two. If you look at the image on the left-- bottom left. It's actually a close up. So you'll see it right on the side of where the blade inserts. And you'll see, essentially, the... powdering or the fluffing-- the white region-- is where you're getting that frosting. And you can see, though, inside of it that there's pitting formation. And essentially, the cavitation is starting to gouge out the material. And this can cause pretty significant damage to our turbine runners. Another structure that we generally see affected by cavitation are the draft tubes. And draft tubes-- in case you aren't sure what they are-- They're usually the tubes that are fitted at the end of a turbine runner. And they generally increase the efficiency of the hydroturbine by messing with the pressure of the exiting fluid and changing the velocity. What you see in these images is corrosion. The rust look is actually corrosion that has begun acting on the pitted surfaces. A lot of times corrosion and cavitation can be seen to occur together. In this case, the coating was likely beaten off by the cavitation and that exposed the underlying steel which was new and fresh and ready to corrode. And as the water goes over it, it takes the metal ions and helps it continue on its path to corrosion. Generally, we see this primarily in the first few feet of our upper draft tubes, where the portions of the draft tube might protrude into the water flow. So here when you look at the image on the left, you can actually see a protruding portion of the draft tube that's actually inside the flow. And that'll create the vortex and the pressure change necessary to cavitate, right beyond that. The picture in the middle is an up-close, in-depth look where you can see the pitting and really just the gouging out of the material. And the corrosion of course settling on top of it. Our next structure that we tend to see this on is our butterfly valves. These can be very massive. Here is one where you can actually see Dr.

Skaja standing in front of it. And it's actually a good example of where cavitation would occur slightly downstream of the point of origin. So what happens with these butterfly valves-- which are used as on and off valves-- They have a rotating leaf or disk inside of them. And they're used for safety and maintenance purposes. But what happens is, when the valve is closed, it will actually start leaking on the side of it. So water will start spraying out as it leaks. And that changes the water pressure. So the spray from the butterfly valve is actually spraying onto the sidewall. And the side wall is where you see the evidence of cavitation. So if you look at the picture on the left, it's actually a really zoomed-in view of the side wall. And you can see that the cavitation and erosion aspect... Basically, where the water is cavitating in such a way to start gouging out the material there. So before we started our research, we really wanted to dive into what Reclamation currently uses for its cavitation resistance. I already introduced to you an application where we use stainless steel weld overlays on our turbine runners. Other options currently consist of using just stainless steel for some of our material. Stainless steel is a lot more cavitation resistant 'cause it's got a work hardening aspect to it. So as it gets beat up, it hardens more. And also, it's got a... a content-- chromium-- and that tends to help it be resistant from a corrosion aspect. So there's other alloys-- the nickel alloy too-- that's present in it. And that helps it with the cavitation resistance. So other materials that we use, we do have an elastomeric coating that we have seen used as a repair material. We've also seen ceramic filled epoxy coatings in some of these instances as well. The picture on this slide is actually of the elastomeric coating. To start off with, the first phase of our research involved developing a testing methodology and apparatus to compare samples in terms of how cavitation resistant they are. So we first started off with an ASTM jet cavitation device. This is actually part of an ASTM standard. We actually found it was quite cumbersome to get operational. The standoff distance was an issue. If you look at the picture on the bottom right, that is actually the chamber where cavitation is occurring. It's a very tight jet that basically smashes into the sample. And cavitates it out. One of the issues we found with this-- not only was it cumbersome-- but it really wasn't representative of field sample size and test condition. This wasn't really showing us what we see in the field. And so we wanted to look at options that would represent that better. The Venturi cavitation apparatus actually was in storage. And they had used this back in the 70s here at Reclamation. And they were using it to test different materials like neoprene and things like that for cavitation resistance. The issue we found was that it was a very slow test. It took 180 hours for just an aluminum sample to cavitate out. And aluminum is one of the softer materials. So, we figured that wasn't super practical for obtaining enough statistically relevant samples. We tend to like doing things in triplicate so that we can have data and show some kind of consistency for the materials that we are testing. What's interesting, though, about the Venturi cavitation apparatus is-- it has a fixed flow rate where the inner shape of the apparatus has a specific size and shape that creates a given pressure change to the vapor pressure of your water. The calculated cavitation region is actually designed in such a way to occur at the location of where you're putting your samples. It was actually designed to create cavitation in a specified location. We ended up settling on a pressure washer jet test. This was something that was being used in the Hydraulics Lab here at Reclamation. So we decided to modify it and adapt it for our purposes. Essentially it had a fixed nozzle. You could attach two pressure washers and run two tests at the same time. You can see in the bottom images that there are two spray nozzles, one on the left and one on the right. So you could be running two tests at the same time. At the top right you can see how the jet action from the nozzle is happening to your sample. We found that this was actually a field representable size. And... it was actually a good rate of testing to allow for us to do a lot of samples. We did have to hone in on our flow rate and that took a bit of work. But now we've pretty much settled on that. Now I'm gonna go ahead and get into the materials research aspect of what we have been doing in our research. We wanted to start with some baselines. So we used a steel sample to start with and we ran it at different flow rates. What we found was that when you were bouncing between flow rates... we ended up picking three different types of flow rates. One was 5 gallons per minute. One was 2.6 gallons per minute, which was the next one of choice. And then we settled on 3.5. And what we found was that the 5 gallons per minute was too aggressive and it was... It almost appeared to be introducing different failure modes that we wouldn't normally see. And so, we didn't want to be subjecting our samples to that. 'Cause it's not really representative of what's happening in the field when you're introducing different failure modes. It is an accelerated test, so that is something that can be problematic in accelerated testing. When we dropped to 2.6 gallons per minute, we actually found that steel wasn't cavitating much at all. Actually, it didn't. So, we knew that was too soft and gentle. At that point we could've been using the Venturi testing apparatus and have it take 180 hours to see anything [!]. But that would've been for aluminum sample, so maybe double the time and that would be your steel. So that just wasn't feasible. So when we settled on the 3.5 gallons per minute, we saw that it had a nice amount of frosting happening on the surface. And you could actually see slight pitting beginning to happen in that cavitation zone. We also did stainless steel baselines. A lot of our materials-- our metallic materials-- will have this as a base material. Not all of them, but especially for our turbine runners, we actually will use the stainless steel as the base material. And so we looked at this. And stainless steel is naturally supposed to be cavitation resistant. It's got the chromium and nickel that I was telling you about earlier, and those are the alloying components in it. And we tested it at 5 gallons per minute and it was pretty aggressive. It was beating it up after about a week of testing-- 40 hours. So then when we changed it and adjusted it, we did the 3.5 gallons per minute and found that it created... frosting on it and... I thought it was interesting that the cavitation zone was actually outside of the jets, so it traveled a little bit. Keep in mind, the steel has a work hardening aspect to it. So it actually gets harder as you beat it up. So, as the cavitation is occurring, it's actually getting harder. But that's not always helpful to prevent cavitation further down the line. Once we got through our baseline, we really wanted to look at some cold spray options and see... Kind of the reason for this is 'cause there's a big push to try out cold spray. And... you know, we thought, well why not? The testing that we're doing is the perfect way to test for this. The cold spray is a process that really uses high velocity particles and sprays it onto a substrate. So the bonding becomes very, very strong-- mechanical bond-- between. the substrate and the cold spray. There is a transition zone, but it happens slowly between the two. And so... When we ran the cold spray-- it was a 316 stainless steel cold spray to try and make it as... similar as possible to the base material, which was stainless. We found that it failed at 60 hours. But it didn't fail catastrophically. And of course in this case, we had tested it at the 5 gallons per minute. And in order to really establish if this is a viable option, we want to re-run it at 3.5 gallons per minute. Although, we are finding it difficult to procure more samples to do this. So we might not be able to include that in our final analysis. We looked at thermal spray. This was a super nickel alloy version of thermal spray. And it performed... Basically, it wore away after 7 hours. And 5 hours for the two samples. So it really didn't last very long. But, we were also running it at the 5 gallons per minute. We could look at it again at 3.5 gallons per minute. But we're also running into the same trouble that we did with the cold spray. It's hard to procure the samples. The nickel alloy itself is supposed to increase your cavitation resistance. So that's why it's super nickel alloy. And thermal spray is different from the cold spray in that you are essentially using heat instead of high velocity. And you're melting particles onto the substrate. And you're still using acceleration to apply them, but it's not high velocity like the cold spray. About this time we were thinking, alright... let's try out some coatings that actually might give us... some other results. And it might be a viable option. So, we had a number of coating samples that we worked with. They were during our testing phase where we ran them at 2.6 gallons per minute. They still need to be re-run at 3.5 gallons per minute. But we were testing a lot of different ceramic epoxies, polyurethane elastomers, and we also tested the US Army Corps of Engineers vinyl coating system. What you see here is that the ceramic epoxy and the polyurethane elastomer had frosting. And so those we were willing to look at further. The two on the top-- the ceramic epoxy and the vinyl-- already pitted when you ran them at 2.6 gallons per minute, which wasn't even cavitating steel. So those we ended up axing out of our testing rubric. So here's an example of the polyurethane elastomer when we ran it at the 2.6 gallons per minute. And I had just showed that on the previous slide, it was one of our strong contenders. So we ran it at 3.5 gallons per minute. And these are all being done for 40 hours now that we settled on 3.5 gallons per minute. And what you notice here is how the elastomer stays together around the area of the jet damage. So we found that elastomers do have the tendency to hold together very well under an impact condition. And they don't shred apart. So it's depending on the coating elastomer and the formulation and all of that. We can find, and have found, some potential candidates that hold together and are also strong in their adhesion to the substrate. And this would be a viable way to protect... our structures. Here are some results that we had. So we did this 2.6 gallons per minute testing. This was prior to COVID. And a lot of these samples, we need to re-run at 3.5 gallon per minute. And we did, so far, with the polyurethane elastomer. We found that that went to 200 hours. And we had to terminate the test because it just wasn't degrading. We also found that the one of the ceramic filled epoxies had a time to failure of 100. Now, since this testing-- now that we're doing 3.5 gallons per minute-- we're actually settling on just doing a 40-hour testing. That's primarily just to get through our sample numbers, and we can weed out a lot of them and keep the ones that are most promising and keep running them. We also want to do our triplicates. We can make sure that they all kind of fall in the same... Behavior. We have found, though, that your application method that you use for your coating, whichever coating it is, matters significantly. So, if you're playing around with cure time, if you're looking at the compatibility of primer or topcoat... coating type compatibility with surface underneath, and their compatibility with each other... Also whatever your recoat windows are... And whether or not it gets good adhesion. There's a lot of different factors that are affected by how you apply these. So sometimes what we have to do is look at how our application method could change to better optimize the coating performance. And that's not always easy to do, and generally tends to require a lot of samples with different parameters for each, so that you can kind of hone in on your most optimal coating system and application. So, we found for our 2021-22 research that testing really didn't reveal damage to steel at 2.6 gallons per minute. So we couldn't use the 2.6, it was too gentle. We found the 5 gallons per minute was too aggressive. So we settled on that 3.5 gallons per minute. And we're doing a lot of re-runs for some of our samples to try and... get a good dataset. We also-- during our FY21-22 research-- we're focusing and shifting to elastomer coatings. So far, some of our planned tests-- we are going to test the stainless steel weld overlay. We do want that as a baseline as well. That's important for our hydropower folks. That's important for the turbine runners. We have some polysulfide epoxy formulas, which are elastomeric. We also have seven elastomeric cavitation repair materials we'd like to look at. And if we can get ahold of samples, we would like to re-run our cold spray and thermal spray... What we found also... in concluding our research-- so one of the most-- one of the more difficult aspects was settling on how you would determine the best way of measuring and comparing samples to each other. So we tried mass loss. But we found that the coating-- or thin layer of the cold spray and thermal spray even-- You cannot get a useful mass loss amount because your original substrate is so much heavier. So we couldn't use mass loss like you would with an ASTM apparatus. The ASTM apparatus I told you about at the beginning. So we ended up settling on a time to failure-- How long did it take for us to see failure? So failure, for us, looks like-- on a metal substrate of some kind or something that is more of a metallic substrate-- the failure is represented by the frosting and the beginning of pitting that you see. And that would tell us it's beginning to fail there. Coatings, however, are a little bit different. So you watch-- basically, we watch as the coating's breaking apart. And when the coating goes all the way through to the substrate, that's how we determine time to failure. So in that case, I guess if you were looking at a combined substrate-coating formulation. Say you had stainless steel and you had your coating. You could potentially assume that the time to failure for your coating would happen before the time to failure for your stainless steel. So you're adding that extra amount of time. Although that's not necessarily true in every sense because the substrate underneath the coating is experiencing... effects from the impact happening to the coating. Now, the reason why we like the elastomeric coatings is because they have a tendency to absorb the impact energy and distribute them nicely. Whereas a harder... coating-- or a harder, more brittle one-- would drive the impact pretty hard in the substrate at that location. And we kind of want to avoid that. So, another issue is that... elastomeric coatings have problems with delamination. They don't always adhere well to their substrates or primers or anything else like that. Sometimes they're really good at just... cohesion where they adhere to themselves, and not necessarily adhesion where they're adhering to the substrate. And this is an issue for some elastomers because you could have cavitation happening and then it would just rip off a whole sheet. And we want to avoid that. So we have to add the high flow adhesion testing to check for this. And we haven't started that portion of the testing yet. But that will be... part of our research goal for the next FY-- fiscal year. So here, I'm gonna leave my email and Allen Skaja's email. And you are free to contact us if you have any ideas or suggestions or materials you want us to look at. And... For now, I'm going to go ahead and answer any questions that you guys may have.

>> Grace Weber: Thanks, Chrissy. We've already had some questions rolling in, but everyone else please continue to submit any questions and we'll address as many as we can. So, first question: What industries or applications that are applicable to Reclamation's mission are using the cold spray material?

>> Dr. Henderson: So, Reclamation itself... I do not believe that we have been using it yet. We're looking at it as a possible option. Cold spray is alleged to be good at a lot of different things. Maybe corrosion resistance. And it really depends on your material that you're spraying and what properties you're going for. But... you can use them-- the idea is for corrosion protection. They might even use them for applications related to the auto industry or... there's a lot of different industries that possibly could use this. I don't know of any yet in Reclamation that is using it. I know that we are researching it. We are looking at it for cavitation purposes and corrosion purposes. And without the extra testing, we can't say for sure or give concluding remarks about how that would be used-- if it would be a safe and viable option for cavitation.

>> Grace Weber: Alright, next question: what is the cavitation jet orientation relative to the surface?

>> Dr. Henderson: I believe-- and I would have to verify this with our hydraulics engineer-- but I believe it's around 30 degrees. And so, a lot of our testing early on we had to find an optimal orientation for it. And then we had to deal with the flow rate. But finding the orientation wasn't too bad.

>> Grace Weber: Okay. Did you test nickel aluminum bronze? It is considered by some industries as having better cavitation resistance than the 304 or 316 stainless steels.

>> Dr. Henderson: We have not tested that yet. If we can get samples, we'd definitely add it to our testing matrix. I believe this potential combination is something that the military has used or tried. I could be wrong about that, but um... If we could get ahold of samples, then yeah, we would go ahead and look at it.

>> Grace Weber: Okay, this is a multi-part question: What are the test water properties? pH, any solubles? And what are the relative spray pressures, rather than the flow rates?

>> Dr. Henderson: So... we look at the spray pressures... we're looking more at the flow rates side of it. That's how the hydraulics folks have been reporting it to us as they run it. Um... Let's see, the test water properties... We are just using house water 'cause we have a facility with a giant sump underneath us. Essentially a big water reservoir that we use for a lot of our hydraulics modeling and testing that we do. And so we're just pulling water from that. We're basically just recycling it. I have not looked at the water properties per se. So I do not know what the pH is of it, currently, and I don't know if it's got like chlorides and sulfates. And what percentages they're in. But it's probably got some other stuff too, since we're-- it's basically just being used over and over.

>> Grace Weber: Okay... What about plastic materials as opposed to a coated metal material?

>> Dr. Henderson: So in this case, I'm thinking what you're asking is, can you do this on top of a plastic substrate rather than just metal substrate? So far we've only looked at metal substrates and we've only looked at concrete substrates in our cavitation testing here at Reclamation. We have not looked at plastic as a base material 'cause we generally don't work with those or consider them as part of our high-risk infrastructure that we want to protect.

>> Grace Weber: The next question: what is the cost to have someone come out and examine or perform applications and is there a contact for that?

>> Dr. Henderson: So, you can talk to Dr. Allen Skaja. He's actually got a lot of connections where... we have... things like this set up. I would say, if I would use an example in Reclamation, we do have a facility where the cavitation damage itself is costing us about $500,000 a day in lost power because we're not using the particular facility's turbine. And then you have to-- you have the lost time in the labor associated with the application, doing the repair. That can run you millions-- a million or so. And so, for us, having this problem addressed, and a feasible option, is going to reduce a lot of cost. And that's really important. As well, as increase-- keeping our safety margins up.

>> Grace Weber: Okay. Next question: Do elastomeric coatings contaminate the base metal, and does that contamination make future weld repair difficult? This, we have not really spent time looking at. I don't know why they would. Although, if you're trying to take them off, that might be-- you might have to do something like a dry ice blast. Depending, like if you're working on a turbine runner, you don't want to be leaving abrasive blasting media and you don't want to damage your blades. So you might have to use like a dry ice blasting technique in order to work on getting the coating off the base material. I... there is a surface prep involved whenever you do a coating application. But I don't know anything in terms of the contamination that would make future weld repair difficult. I think essentially what you have to do is, if you want to do a future weld repair, you have to get all the coating off. So that that's not affecting your weld.

>> Grace Weber: Which category does Enecon fall under?

>> Dr. Henderson: Um... Enecon might... They have a number of different coating types, so... A lot of our research that we have done does involve potential candidates that we have used for some different companies... and products. And we aren't able to share specific details about them to the public yet.

>> Grace Weber: Okay. How were the flow rates used in the tests chosen, and how do those flow rates relate to a real system?

>> Dr. Henderson: So, essentially we had the hydraulics folks hone in on the flow rates... to see if the cavitation damage was representing something we were comfortable with. With the 5 gallons per minute, we were finding that was just too aggressive. Literally destroying your samples. And... introducing... extensive cracking and things like that, that we might not see out in the field. And so we didn't want to introduce that as part of the test matrix. But then, when your flow rates are too low, you're actually finding that you weren't even cavitating steel. And steel cavitates easier than stainless steel, but we do see it cavitate out in the real world. We also picked sample sizes that, essentially, were big enough so that you could create-- you can have an elongated region of... cavitation zone. And you weren't having to worry about edge effects. But with the tiny little ASTM samples, we were-- it was just a jet that was impinging right in the center. And that's not typically what we see. Usually our flow rates are at angles. They're... They spread across the surface in an elongated pattern. And... They all still involve-- our testing is actually a combination of the cavitation and the erosion aspects. The two of them go hand-in-hand. Where the ASTM system was only cavitation. And we actually wanted a little bit of a combination of the two because that is more common to what we're seeing out in the field.

>> Grace Weber: Alright, we still have a couple more questions. Let's see... Are you measuring extent of air entrainment in your jet flow? Does it matter how much air entrainment you have as it relates to extent of cavitation? We are not measuring that, and that is an important aspect when you're dealing with-- especially with the... the turbine runners. There are systems that inject air so that you can actually change the parameters a little bit and you won't be... your cavitation won't be as bad. So, airflow additions... are helpful for some mitigation, just not-- Not all of it.

>> Grace Weber: Okay. Can you use the low ambient pressure chamber to do your testing?

>> Dr. Henderson: Um... So... It's not the air pressure that we're worried about. It's the water pressure. And that has to be created with the water jet itself. So you're creating-- you're dropping your pressures in such a way that you're reaching the vapor pressure so that your bubbles form. And so, it's a water pressure, not an air pressure that we're Working with.

>> Grace Weber: Um, this question... What are the corresponding fluid velocities to the flow rates that you are using?

>> Dr. Henderson: This, I would have to ask our hydraulics folks. They've been reporting it to me as flow rates. So I'd have to find this out from them.

>> Grace Weber: I believe that's all the questions that we had submitted. Um... So, thank you Chrissy for giving that presentation. Do you have any closing statements?

>> Dr. Henderson: Basically, what Allen and I have found through our research is that there are a lot of promising options available. And we are excited about what we're seeing. And we will be continuing this and we love any collaborations with groups or any folks that want to try material. Submit it in and we'll look at it as a potential candidate. And essentially, we feel like we like the direction we're going in. And it could offer some viable alternatives to our hydropower industry and also in our concrete... structures as well. And I just want to say thank you to all of you for joining in today. And if you have questions like I said before, you can. contact either Dr. Skaja or myself. And we will answer your questions or find somebody that can.

>> Grace Weber: Great! Thank you, Chrissy, and thank you everyone for joining!