>> Dr. Skaja: Today, we're going to talk about robotics coatings applications. This has been a very, I guess, big area of application for fast production rates. And contractors have been using this since about 2008 or 2009. But in just the past couple years, some contractors have taken it to the next level and now can do it on steep slope pipelines. So this is relining the interior surfaces. So, what are we saying is robotics coatings? So, this is primarily for the internal pipe. It's where we can do jobs at a much faster rate, much faster application, and they can get in and get out within half of the amount of time, usually, of a typical coatings job. So, it's not necessarily 100% robotics, it's using equipment for automation. So, it's not where... They have people in there doing the manual labor. They're using equipment to increase productivity. So, they can do water jetting, abrasive blasting, as well as the coating application. And the real—when I say robotics, it's not... It's not necessarily like a machine that is used via a control stick or... It can have, uh, a winch system that is controlling it by a specific rate. And not necessarily using a joystick to move it left or right, or you know that type of stuff. There are some equipment that have been developed for that. But I just don't know how fast the production rates will be. They're very new equipment. So, what we're talking about today is just the internal linings of pipes. And there's equipment that can go up to 32-foot diameter. So that pretty much takes care of most of the infrastructure in Reclamation. There's only a few pieces of infrastructure that go above a 32-foot diameter. So, there's a few things that are beneficial for the robotics application. And I would say number one, it is safety. So, if you have a steep incline and you have to be on ropes access, it becomes very challenging to have any sort of high productivity when you're working from a platform and you have a winch system that can lower or raise the platform. And if something happened where there was an emergency situation, having that slow control winch system, you may not be able to get out in time. Or it may take more effort to get the persons to safety. So, using the robotics applications, we're putting fewer people in harm's way. And it is just—it's a much safer application procedure. So, when we're talking about hazards, it's not necessarily like if someone got injured on the job. But we're also talking like hazardous environments such as particulates and solvents. So, the abrasive blasting procedure. We can take a step back and eliminate or reduce the number of people working or exposed to the hazardous material, whether it's the abrasive blasting process itself or the existing condition—existing coating system that is on that structure. So if it was coal tar enamel or lead based paints or what have you. So, the other thing too is, we have proper air flow and continuous monitoring. So, engineering controls to force air through the pipeline so we can control the environment. If employees had to, they can still be on supplied-air respirators. And, you know... I would say, you know, the biggest driving force to find safer methods was this Xcel Energy Cabin Creek Fire that occurred in 2007, where even though the contractor was using 100% solids epoxies, they were using MEK. So, a solvent to clean their equipment and they were atomizing all the solvent into the space. There wasn't adequate ventilation and Um... A fire had broke out. There was poor safety planning and there was no emergency response plan. It was very unfortunate, but five people died inside that penstock due to being trapped above the fire and had no way to escape. So, automation greatly reduces the risk here. And so that is, I would say, the number one benefit. The second benefit is,

you know, there's high productivity. So it benefits the contractor as well as Reclamation. Because We can have shorter outage windows to complete the work. And what that equates to is dollars. So we could be generating power or doing water delivery, and so it's a benefit for both the contractor as well as Reclamation. So, this is—that's compared to a conventional job. So, the photo here is a conventional repair method at Grand Coulee. This was the third power plant. So that penstock is around 40, 45-foot diameter, somewhere in there. You can see me there standing in the foreground of the scaffolding structure, which is on a winch system. And they lower this down the steep portion of the penstock. And there's people standing who would be doing abrasive blasting or surface prep, as well as coating application, off of this platform. Because I was not rope certified, I would not have been able to go on that scaffolding while it was being lowered down. So, it is very time consuming because as you can see, if you had to move between the various levels of that platform, that scaffolding platforms, it takes time to do that. As well as moving your equipment, your hoses, etcetera, to the various platforms. So, the biggest advantage here is, if you use robotics, it's a lot less time-consuming. So, here's a case study that we did. I was basically a consultant on this job—hired as a consultant for the Central Arizona Project to evaluate the coatings and the process for the entire job. And when I first reviewed this job, I thought, man, 100,000 square foot, 12-foot diameter, 2,500 feet in length. I thought, with the slopes, that would require ropes access, as well as a scaffolding system. And they wanted only a 90-day outage. I told them that there is no way that you can get this job completed within that 90 days. And the contractor was on the phone and he said, well, we plan on using robotics application. And we have done similar jobs in less time than this. So, they reassured the client that they could get this job done. With everything, with the drop in elevation and the slopes. And they guaranteed that they could get this job done. And I was skeptical. But in the long run, the contractor was right. They got the job completed in the 90-day outage. With all the complications and various terrain of this environment. Uh, so here's the Mark Wilmer pumping plants and—is there an arrow that I can show?—So, on here—they can see the arrow? Okay. Okay, so here, you can see the various levels. So there's access points right above the powerplant, but water gets pumped all the way up here to the top of the mountain. I don't remember what the mountain name is. It's like Buckskin Mountain, I believe. It pumps all the way up there and there's 824 feet change in elevation. The existing conditions—so this was lined in the 90s—no, 1980s with coal tar enamel. So, it had the really good coal tar enamel, but, yet we had coating delamination almost throughout the entire length of the pipe. And so this was in really bad condition. We're not 100% sure why the coating had failed when, you know, 3 miles down the road at Parker Dam, that lining is the original lining and it has been in place since the 1940s. So, that's 70 years, whereas this application of coal tar, 1980s. So it had about only a 35-year service life. So, the relining plan. So this is Hartman Walsh that won the contract for this. They planned on using robotics. They were going to use waterjet robotics to remove the coal tar enamel. Get it down to bare metal. Use an abrasive blasting to get to near-white or white metal using the modified commercial equipment. And then they had an in-house designed robotic coating machine. So, spin coater. And they had proprietary methods for working on a steep

slope. So, I was never allowed to go inside while they were doing the coating application. Again, I don't have rope certification, so you're limited to what you can do on steep slopes if you do not have those certifications. So, they came in with huge, huge equipment. I had never seen equipment this large before. It was just pretty impressive. Very large air compressors. They had very large generators, dust collectors, pressure pots, vacuums, air dryers. I don't think they really needed the air dryers, but they needed the air conditioners because they did this work Starting in June and went through August. If you've ever been down in this area during those time frames, you're looking at 110 to 115, even 120 degree Fahrenheit temperatures. So, the actual workers enjoy going down into the containments, the confined spaces, because it was at least a 20-degree temperature drop. So, the winch system is kind of what made this whole thing work, especially on the steep slopes. So they could control the rate of the equipment. Whether, you know, they were lowering it or bringing it back up. It was adjustable. They could control the rates. So, I'm assuming that they're—the rate on the abrasive blaster was much slower to get that near-white metal blast compared to the coating application equipment, which, you know, is high productivity. So the water jetting, you know, they could do up to about 100 linear feet in a day of a 12-foot diameter. So you're looking at about 3,600 square feet per shift. Now, they actually ran two shifts per day. They would run two 8-hour shifts per day. So, that meant 16 hours a day, they were working. It is a very fast method to remove coal tar enamel. Especially when it's degraded coal tar enamel. It's effective at removing the residual oils out of that coal tar. And it eliminates, you know, really, the hazardous dust that anybody would be exposed to. So, you didn't get coal tar dust on your your employees because it was wetted down. And in the end, you know, the coal tar debris was the only source of any hazardous waste that they had to get rid of. And I don't even know—I don't know the facts. If the coal tar ended up being actually disposed of as hazardous waste. Because once you test, you basically determine whether it's hazardous or not by the leachables out of that material. So, during the abrasive blasting process—now, these rates were much slower. They were about 50 linear feet per shift. So, about 1,800 square feet per eight hours. And, you know, it's still much faster than if they were to do this manually. So, if you had one abrasive blast person in there suited up on a scaffolding system, tethered off on ropes access, I would be surprised if they could even get half of that surface area blasted in an eight-hour period. So, it's just it's so much faster. You know, it reduces that manual labor. I would say, of the entire process, the abrasive blasting is the most labor intensive if you were to do it conventionally. And it wears on a person. They can probably, you know, really work straight for about two hours before they're just so exhausted that they have to get out. And not only that, but they're in a full blast suit and blast helmet. And if they're working in 90 to 100 degree temperatures, I just can't imagine the heat exhaustion. It's just—so, it's much safer to have them monitoring equipment to do the blasting process. Again, you know they—because the coal tar was removed, now they're only exposed to the blast media dust. So, moving on to the coating application now. There's—we don't have a close up of the actual robot and the reason for this is because it is an in-house design. And we didn't want people being able to see how Hartman Walsh built their robot. But what we have is, you know, they use 100% solids epoxy. So, solvent

free. This was the exact same system that Cabin Creek Fire, they used. But here it's different because they use—Hartman Walsh had used hose bundles, plural component hose bundles, so each component is in a separate line all the way up to near where the robot is before it gets mixed. It goes through a couple mix manifolds and then it's a single feed line to the robot. So, when they had to clean out their equipment, it's basically, they took the mixed manifolds off. And their little whip hose, like 25-foot whip hose. And they took those off and completely replaced them after every shift or every shutdown. And then they took the nozzles off and took those out of the containment. And they could put those in a 5-gallon pail of solvent, or cleaning solvent, and then just clean the guns and the nozzles. So, this was—So, that's the picture on the left. The picture on the right is where they had a trailer set up with the pumps. So, they took the drums of the material, and component A and component B, and they used the pump and they pumped all the material through those hoses to the robot. So, there was no additional pumps inside the containment. Now the—like I said, they went through a lot of material in a very short period of time. So, per day—so this is 2 shifts—they could get 500 linear feet down in a day. 1,800. That was the fastest they were able to go. And this was on steep slope. Again, it was not on flat pipe. You could imagine, you know, maybe even faster on a shallow incline. So, it's just amazing how fast they can do this. So, again—this is sort of a close up. We didn't want to get too close to show how the robot's set up. But They can pump material 800 to 1,000 feet in length. So, from where the pump is, they can pump all that material up to 1,000 feet. Already mentioned the mix manifolds and how they did their production. So, it's just, it was a much safer means and methods approach to applying the coatings at Mark Wilmer. So, here is the final coating product. 60 mils. They were within a couple mils throughout any portion of this pipe. And, you know, after the one-year inspection, and they had zero defects. That is truly impressive because we've done projects where we have, you know, 100 spots that they have to go in and fix. So, just having it—after one year, and no defects, is very impressive. So, it's higher quality and product. So, some other—So, that's the end of the CAP project and how they were able to do that whole project in 90 days. Now, there's some other equipment that has come out on the market in recent years where, you know, it's just neat watching the progression and how companies are developing new technologies. So, there's—the upper left is a small-diameter robot where they put it inside the pipe and then they can pull the hoses and move the robot at a certain rate to get a blasted profile on a small diameter pipe. Um, the center photo is a centrifugal blast unit where it can be either horizontal or vertical. In this case, it's vertical going up the side of a tank. But you get—you have a 2-foot wide path. And they centrifugally blast clean this surface. Again, you get a high productivity rate. And it's all self-contained and there's vacuum hoses sucking up all the dust and whatever the old coating system is. So then the two lower photos. These are blasting units that have either—so, the one on the left has a camera. And it's a blast unit that is coupled to a magnetic crawler. So, both of these are magnetic crawler units. And they can abrasive blast the steel surface. And everything is controlled by an Xbox controller. So there's... Uh, so we have various techniques now where, hey, if you have to do spot repair on a vertical or horizontal surface or even in a pipe, it looks like they might be able to accommodate those situations. Other

technologies? Uh, so there's... various levels of coating machines designs. So there's—one is called ROI 360. And then there's other ones. So there's another one called robotic pipe repair, as well as this PRD company. So there's various techniques and styles. I'm going to show you just a couple videos here. Now this is for the exterior of pipe joints. Now, this is very slow. I think that there are techniques, if they weren't doing a vacuum blast, that you could go much faster. But it's what is potentially out there for the future. So, we have a couple projects where we're doing the exterior of pipe. And maybe this is the next methods for doing these coating repairs. I could envision seeing this now on a system where it's on a um, an extension system. So now it would also move in the Z-direction, not just circumference. And I don't know what the future may hold. This is very interesting technology. It looks like it's very fast coating application. I would assume that you could do something similar for the abrasive blasting. So, now we have the benefits for the contractor. I mean the list is quite extensive. So, you're reducing the exposure, you're reducing the number of employees in the confined space that may be on ropes access. You're reducing that fatigue of each employee because you're having the equipment do most of the heavy lifting. You have improved surface cleanliness consistency, as well as coating thickness control. Fewer holidays, so less touch-up work. Less fuel consumption because you're doing this at a much faster production. You have... Less, so reduced amount of personal PPE purchasing. Reduced blast media, as well as coating material waste. And your fast return to service. So, they're moving on to the next job. For Reclamation, I can see the benefits as, you know, we're— This type of application, we have less exposure to employees and contractors, so less hazardous conditions. You have a higher quality end product, so fewer holidays that may develop. You have less disturbance to the pipe interior. So, you have lower levels of scaffolding or equipment and people mobilization. Shorter outage windows. So this is the big thing. You know, getting that work done and the plant back in operation. Reduced safety liability, as well as reduced labor costs. Because even though, you know, we talk about the contractor costs, we also have employees monitoring these contractors. So, there's a savings there as well.

>> Stephanie Prochaska: So, what is field EIS, or electrochemical impedance spectroscopy? Essentially, it is a frequency-dependent application of Ohm's Law. And the value that we get from running the test that is most important to us is called the impedance magnitude. And that is derived from the resulting voltage and current data that we get from the EIS test. Impedance itself is a measure of how much a circuit is resisting current, or in our case, the flow of electrons through the coating. So, when we get large impedances, that means that the coating is providing a greater protection against corrosion, whereas smaller impedances can tell us that the coating isn't—the coating is allowing a lot of electrons to flow through and is providing poor corrosion protection. Field EIS, again, is a quantitative approach to estimating the remaining service life of a coating. And we use field EIS on defect-free linings. And when we get impedance values that are above 10^8 ohms at 0.1 hertz, we would consider that to be a good coating that is still providing good protection. The figure just shows our basic field setup. We use a laptop, the potentiostat itself, three different electrodes, and then—you can't really see them, but we have 3

test cells that are adhered to the pipe wall. So, why would somebody want to use field EIS testing on their structure? Again, it is a method that can complement visual inspections. So while a visual inspection qualifies coating damage that we can see, EIS can quantify undamaged coating performance. So again, this is a test that we only run on visually undamaged coating. Just because the coating looks good doesn't necessarily mean that it is performing well. It is a method for us to make decisions based on hard data. We can use it to develop a threshold for coating maintenance for a particular structure. If we can't recoat the entire structure, we can use it to identify only certain areas that should be recoated that are in the most need for that recoating. And in addition, we can also use it on newly coated structures before they go into service to ensure that the coating that was just applied is performing as expected. And in these situations, we wouldn't recommend doing it on every single coatings job. Maybe just on those where we have some doubts about how the coating was applied or possible high-profile situations where the coating needs to be in excellent condition right after application. So, again, EIS can be used to test for the remaining service life. On this slide, I'll just explain a little bit about how we set up the test and what it actually involves. So, again, we use temporary cups that are glued to the coating itself at regular intervals throughout a pipe or a siphon. And those cups are filled with an electrolyte solution. And then we perform the test. So, the test can take between two to five minutes depending on the frequency that we run the test down to. When we first started doing these EIS surveys, we would run the test from 10^5 to 0.5 hertz. That would take about 5 minutes. In our more recent surveys that we've done, we've only been running it down to about 0.1 hertz, and that has shaved off about two to three minutes from our test time. And we still get the same useful data, just in a shorter test time. So, the setup is really the most time- consuming part of doing an EIS survey, and it takes about one to two days depending on the number of test locations. What we have to do is first clean the area where we want to do the test, apply the adhesive to the cups, and attach the cups to the surface. The adhesive needs a few hours to dry and then we can come back and fill the cups with our electrolyte solution. Now, depending on the coating and depending on how saturated with water it already is, will determine how long we need to leave that electrolyte solution in the cups before we can actually run the test. If it is a newly applied coating or if the structure or feature has been dewatered for many days, we might need to leave the water in the cups to saturate overnight. Whereas if the structure had just been dewatered earlier that day, we don't need to leave the water in the cups for as long. So it is only after the coating is resaturated that we can then perform the test. And again, that will take about two to three minutes. So, the test is performed at an open circuit potential across many frequencies. We take five data points per frequency over a range of frequencies, as shown in the table. So, one of the first EIS surveys that we did was the interior of a large siphon and we were able to collect data at 42 pipe locations. And we tried our best to get one EIS test per every four pipe segments. So, the results that we get are in the form of what is called a Bode plot and that is the figure shown here. Every curve in this figure is one dataset for one location. So, the Bode plot shows the impedance magnitude versus the measurement frequency. And again, we are most concerned with the frequency that is the very lowest. So, in this case, we are concerned with that

very, very first data point at 0.05 hertz. So, we like to consider that impedance magnitudes that are around 10^8 ohms and higher are where the coating is showing capacitive behavior and it is performing well at preventing corrosion. Anything below 10^8 into 10^7 ohms and below, we would consider the coating to be performing like a resistor. So, it is allowing a lot of ions and water to flow through the coating. And so we can relate this to whether or not these locations need to have the coating replaced by saying that anything above 10^9 ohms, the coating is good and shouldn't be replaced, whereas around 10^8 and below, we would recommend replacing the coating in those locations. So, what does this Bode plot tell us about exactly where in the siphon or the pipe the coating needs to be replaced? If we plot the data in a different way, which is impedance magnitude versus pipe segment number where we collected that value, we get this profile of the entire length of the pipe and exactly where the coating is performing poorly. So, in this particular example, we recommended that the coating is replaced on segments 20 through 90, and then at segment 200. Now, if we had the pre-service values for this particular structure—that is, if we had been able to run an EIS survey before it went into service for the very first time, we could have actually calculated a degradation rate per pipe segment. Another way that we can display this data that complements the previous figure, is to use a 10% probability plot. So, we would recommend recoating if the statistical analysis average is less than the threshold value, which we have identified to be 10^8 ohms. Now, in this particular case, we have two linear fits that we ran. The first one, the one that bisects the probability curve in two places, that is where we did this simulation for all of the data throughout the entire pipe. And it is nonlinear, so that suggests that there is a bias in the data. Therefore, there is non-uniform degradation occurring in the pipe. And that is similar to what we saw in that previous figure, where some portions were much more degraded than others. So then, our second line that we fit was only to the good data. And since that is a linear fit, we can assume that that portion of the pipe is degrading—or, the coating in that portion of the pipe is degrading uniformly. So, in conclusion, we found that the majority of the pipe in this case is in good condition and the full relining is only needed in the select sections that we pointed out in the previous figure, and then the ones that came up in this probability plot. Some other ways we can manipulate the data are by correlating it with the pipe profile. So, if you see the inset in this figure, that is the profile of the siphon. So, the siphon's elevation changed about 1,000 feet and this profile shows that change. Now, what was really interesting that we found in this particular EIS survey—it hasn't really matched this well for other surveys that we've done—but just as an example here, we found that the degradation of the coating closely followed the siphon's profile. Ignore that red line, that is just a 5-point adjacent averaging that we did for all of the data. But you can see that where the siphon profile changes quite drastically, so does the impedance magnitude values. And that is for areas where the elevation is increasing and also decreasing quite drastically. So, we can use this type of correlation to kind of figure out some failure mechanisms of the coating. So, for example, we are assuming here that where the areas of elevation change exhibited more damage, that could have been due to sediment scouring or different flow rates. And this can help us when we are specifying coatings to replace this coating system with because we can say, okay, there might be

some sediment scouring here, so maybe we should replace it with a more abrasive resistant coating. Whereas in other portions of the siphon, we're not really seeing that, so we might not be able to—we might not need to use those types of coatings in those areas. So, in summary, field EIS testing reveals the corrosion protection ability of visibly defect-free lining. And we can use it to estimate the remaining service life for decision-making using low frequency impedance magnitude versus location and probability plots. And we'd also like to announce that we have a technical publication, brand new, on field EIS and how it works and how it could be beneficial for you or your facility. And that is now available from us, I believe it's on the website. So, thank you. Are there any questions? Here's our resources for both my presentation at the bottom, and then Allen's robotic presentation. The TSC's Materials and Corrosion Laboratory staff are also a great resource if you have any further questions. And this is the updated list of our current staff.