>> Chrissy Henderson: Thank you, Jessica, for that introduction. I appreciate that all of you are out here listening to this webinar. And we hope that it will be very informative. And we will be focusing specifically on tanks. And... So, specifically today, what we want to do is focus on several important objectives. We're going to review corrosion. It won't be very extensive because there are previous webinars on that topic. We're going to cover the types of tanks that are used by Reclamation. We're gonna go over some coatings considerations for tanks, cathodic protection consideration for tanks, some of the CP designs that we use, and the testing and inspection. So, as a review of corrosion, generally speaking, corrosion is a pretty significant problem in our industry. And Reclamation even has an entire group dedicated to mitigating corrosion. So, as a general starting point, corrosion, the reason why it happens is because metals, they tend to be removed from their natural state in the environment. And they go through a series of processing. And so the more that you have to process metal, you're removing it further from its natural state. And it always wants to go back to its natural state when it's in the environment. So, you could get noble metals like gold and silver, platinum. Those tend not to be super reactive because they're already in their natural state. But other ones, like aluminum, go through significant amount of processing. So you actually, when you re expose it to its natural environment, it wants to go back to its original state. That is the whole process of corrosion, why it happens. Corrosion itself is an electrochemical reaction between a metal and an electrolyte. So, typically at Reclamation we use steel and see some other ones as well. And our electrolyte will be soil or water. You could have other electrolytes but for Reclamation's purposes, it's generally soil and water. So, you need to have four required components in order for this electrochemical reaction to occur. And we use the acronym "ACME". So, that represents the anode, that's the corroding material, the cathode, which is your protected material, your metallic return path, and your electrolyte. You absolutely have to have all four components in order for corrosion to occur. So, mitigation strategies typically resolve to remove one of those components and that would stop the corroding reaction. You'll see in this image here that we have on the slide, the general area where you can see this gaping hole, so to speak. That would typically be what you would see in your metal that's being removed. So, all the electrons present in this area are moving away and so you're having your metal loss. You get the byproduct, the rusting that you see. And you can see in the slide that you have your electrolyte, which is the water. It can also be the soil. And your corroding material. In our case, it would be the tank wall. So, the different forms of corrosion that you would typically see in a tank. You'll generally see—you could see uniform or general attack. Those aren't as common because of the mitigation strategies we use. But oftentimes when you're out in public or whatnot and you see general corrosion, that is typically what people consider the rusting that they see on the surface. There's also galvanic corrosion. So, you have dissimilar metals in this case. So, when you combine two metals that are electrically reactive with each other, they create a potential difference between each other. And you create a corrosion reaction there. Crevice corrosion, you can see that when you're dealing with things like washers or maybe rivets. And if you get inside underneath some of those inaccessible areas, you could get some localized crevice corrosion inside there. Pitting is also a localized form of corrosion. You can see this when you

have a coated surface with a defect, and then you have a localized, concentrated area of corrosion that pits into your surface. And this can be particularly troublesome for tanks. When dealing with corrosion, the idea is to create a barrier between the metal and the electrolyte. If you remember our acronym, ACME, if you remove any of those components, you stop corrosion. So you want to create that barrier. And that's what the coating does for us. You can also eliminate potential differences on the structure's surface. And that's what the whole idea behind cathodic protection is. And we'll be going over both of these later in this talk. You also want to avoid use of dissimilar metals. And, specific to tanks, when you're creating a tank foundation base, you have to make sure that your soil is compacted evenly so that you don't end up with an oxygen concentration cell forming in any of those areas underneath your tank base. For really good corrosion management, we like to say that the most effective corrosion protection system involves a really good bonded coating and cathodic protection. Coatings are our primary corrosion protection for the tanks. Cathodic protection helps you extend the life of the tank and the life of the coating by maximizing time between recoats and preventing a lot of that pinhole pitting corrosion that happens at coating defects. The right corrosion mitigation system typically involves an upfront investment that will reduce your long-term O&M cost. Because this is not a talk that's specifically focusing on corrosion, if you have more questions about corrosion in general, we do have previous webinars that can cover that. And I've included Jessica Torrey's contact information and she can get you those webinars and many of the talks that have been done in the past. So, because we are focusing on tanks, we are going to spend some time here discussing the types of tanks that are typical for Reclamation. It can be broken up in two broad categories. We have our above ground storage tanks. These are the most commonly used ones. In Reclamation we also have underground storage tanks. Reclamation does not commonly use these types. Typically, we don't like to bury steel tanks. If we do have an underground storage tank, we might put them in vaults, as you see in the picture there. And general rule of thumb, if the tanks are larger than 500,000 gallons, we like to use steel. If—or, if they're less than, I'm sorry. If they're larger, we use concrete. And this is because construction is more expensive, but it is cheaper to maintain. Now, also, with that in mind, concrete tanks are not exempt from corrosion. They do have issues related to chemistry. So, we always recommend sulfate testing for any of your concrete tanks, so we can make sure that you don't have sulfate in soil that your tank will be sitting on or in the water that is stored in them as well. This webinar, in general, will focus on above ground steel storage tanks. So, the types of tanks that you'll see. Air chambers. These are the pressurized ones. They are always welded steel, due to pressure conditions. We really don't like to damage the skin of the tank since it is part of holding it together and keeping its integrity intact. They generally follow a pill-like shape, which you see in the picture. They can also be spherical. These are ideal shapes for pressure vessels. You tend to want to avoid the cylindrical shape when dealing with pressure vessels. We also have surge tanks. And these tanks are used to mitigate pressure surges within a system. So, as your water surges in or out, the tank can rise and fall in level and sort of act like a dampener that prevents major surges from running through the system. The surge tanks do have to be at a high point of your line because they are gravity based.

They can be open to the atmosphere, as the picture shows, or they can be covered. Other types of tanks, and these three tend to be very, very similar. They are similar in their design in terms of being steel, closed/open top, short or tall, but their names are all based on their function in the system. Forebay tanks are, as you can see in the picture here, they're pond-like tanks at the top of a penstock. Because a penstock runs—sends water towards your turbines—you need to protect the turbine from any kind of debris and material that could damage them. So, the forebay tank allows for particle settling before the liquid, or in this case water, would enter the penstocks. Regulating tanks and distribution tanks are basically storage tanks. And they just hold large reservoirs of water. In general, there's a lot of different types of tanks, different kinds of construction. Here, you'll see the bolted style. You can see in the image on the left that you have corrosion occurring in the bolts here. You can also see the image next to it is a ladder that's bolted to the wall. We also have welded tanks. So, the arrow is pointing towards a welded section that's actually begun to corrode. So, you can see that darker brown region is actually corrosion occurring to a weld. So, both of those images up top there are of welds. We tend to have both. And also, we will see—we've been increasing the number of composite tanks that we've been utilizing in Reclamation Composites are still a fairly new type of construction for Reclamation. So, we are slowly implementing it. But we do have some composite tanks. These two are acid and base tanks, and they're composites for that reason. We have concrete. Those, you can see that image there, is a concrete tank that's being constructed. But we'll also see concrete wire-wrapped tanks as well. And those are present in Reclamation. So, now what we'll do is we'll go over some of the coatings considerations for your tanks. So, protective coatings are our primary means employed by Reclamation to control corrosion. This is our primary method. So we use the coating, you'll see in this image on the left, we do have a whole coatings laboratory where we do testing—coupon testing of a number of different coatings. And we watch their performance over a service life period—time frame. And we essentially evaluate coatings for different applications within Reclamation. So, because the coating acts as a barrier between the steel tank and the water, it helps to electrically isolate the tank from the electrolyte. So then, your ACME acronym is coming back into play. You're removing one of the elements of that. Some examples of coatings that we use for tanks. Some of the waterborne epoxies, acrylics, mastics, high solids epoxies and urethanes. And these are usually selected based on your application. So, is the coating suitable for your storage application that you have in mind? Is it okay to use a particular coating in, say, a potable water situation? If you have a potable water situation, then the requirements are a lot more stringent. And they follow the National Sanitation Foundation standard, the ANSI and NSF 61. And these specify the types that can be used for this application. Some examples, epoxies. Epoxies tend to be used in these type of potable water situation. Will you have a harsh environment present? Water can vary largely in its pH, its temperature, in dissolved solids, soluble salts, hardness. This essentially can create an extremely aggressive environment in the area below the water line. So, you need coatings that are specific to that particular application or harsh chemistries. Are we dealing with sludge or other abrasive particulates? Are you going to have erosion issues? And a lot of these considerations will

determine what type of coating system is used on your tank. One of the key important factors when dealing with coatings for your tank is your proper surface preparation. This is critical for making sure that your tank lasts. Definition of the surface prep is the cleaning of metal to ensure the best possible bond between your coating and the surface. A coating's service life is directly related to this. Surface prep can include removal of oils and soluble salts from the surface. You really want to get a good adhesion of your coating to your surface. You can't do that when you have these present. Also, it's really important to build a good surface profile so that your coating could adhere to the surface. And there are standards that specify a lot of these particular aspects. And our coatings team takes care of that. An example of—you can use abrasive blasting to create a surface profile. And you can see in these images, they're doing a lot of their surface prep. One thing that you want to be aware of is, you do not want to use—well, you would like to reduce the amount of use of a dark colored logo on the side of your tank. The reason for this is because under solar exposure, the dark logo can actually heat up. When it heats up, you can create a blistering effect on the inside of your tank where the logo is located. So, it's—general rule of thumb is beware of using dark colored logos on your tank. Now we're going to review the cathodic protection considerations for your tank. Cathodic protection is essentially a technique that is used to control the corrosion of your metal surface by essentially taking all the anodic areas of your surface and turning them all into cathodes. You're taking all the material you have and everything you're trying to protect and you're creating cathodes out of them all, so that you're doing what our acronym ACME—you're removing one of those elements then. So, as soon as you remove that anode, then you stop corrosion. So, that is the goal with cathodic protection. So, in cathodic protection, current will flow through your electrolyte, move from your anode to your tank. The idea behind this is they use an anode to transfer current. So, you can use that with a galvanic anode. And you polarize your tank in order to eliminate any potential differences that you have between your anodic and cathodic areas. So, this will drastically reduce your corrosion rate, or at least that's the hope. Electrons are provided from the source. So, if you remember that image that I showed you earlier where you had the hole that was forming in the pipe wall and the electrons were moving away from it. Here what you're doing is you're providing electrons to your tank by using the sacrificial anodes, or you can use it via a rectifier. So, when you use a rectifier, in that case you have an impressed current cathodic protection system. CP—and I'll just reiterate this again, cathodic protection, also called CP—works in conjunction with coatings to protect your tanks at all of the holidays and any defects that you have in your coating. And this will prevent any undercutting of your coating, and it will help make it last. In a galvanic anode cathodic protection system, it's also called a sacrificial anode cathodic protection system. Essentially what you're doing is creating a galvanic corrosion cell. So, this is how you attempt to protect your structure, and then you use the sacrificial material to prevent corrosion of your tank. One key to this is that you have to have both your tank and the anode in contact with your electrolyte. If one of them is out of it, you no longer have ACME working for you. Or, you have the full corrosion cell happening. Features, the reason why we use this galvanic system. We like using it because of your low current requirements. You can use it if you have smaller surface

areas to protect. If you're in a situation where you don't have external power, you can use this method. It's also a lot lower maintenance compared to the impressed current systems. In the images here, you can see new magnesium anodes, as well as the old ones being consumed. And then you can also see the zinc anodes. So, these are just two of them that I provided on the slide, so you can see a general—what they might look like. We also have sacrificial string anodes. This could be an array of anodes to give you the length that you need from the top of your tank to the bottom. And it sort of allows you to space them out. We use a wire rope or cable—tension cable connection to hold them together. You never, ever want to use the cables that come with your anodes to attach to your structure. Those are not load-bearing cables. So, you never want to use them to hold any weight in this type of a system. So, for soil and freshwater, typically we use magnesium and zinc. Brackish, we'll start dealing with more of the aluminum and zinc side. But it's important to note that zinc is not something that you can use in a potable water tank. For impressed current CP systems, generally when we have higher current requirements, we want to use this type of system. Larger structures, much larger tanks or poorly coated ones will benefit from impressed current. Also, if you have hanging anode weight issues and you can't have the weight that's associated with a galvanic anode system, then you could use an impressed current system. Here are some of the anodes that are typically present in an impressed current system. You can see a a platinized wire anode that's put in a slotted PVC tube for submersion. And so, this—you could possibly see it if you wanted to have current distribution through the slotted portions of the PVC tube. There's also the graphite anodes, the mixed metal oxide anodes, and there's quite a bit of flexibility associated with the anodes used for impressed current. So, generally speaking, impressed current provides an external power source, and that's what kind of beefs up the system and really provides the power that you need. And essentially it does it through discharging through the anodes into the electrolyte and onto your structure. As is the same case with the galvanic system, both your structure and the anode must be in contact with the electrolyte. You can't have one of them outside of that, otherwise you won't have a working corrosion cell. In general, CP system designs for tanks—we have a few that we follow. There are a lot of different options that can be used. So, generally what we want to do is, we want to design a minimum of 20-year service life. So, that is usually our goal. There are a lot of situations where that's not possible. But that is usually our aim. We typically like ease of maintenance and easy replacement. So, that tends to be why we would be more apt to select a galvanic system as opposed to impressed current. One of the things that we do need to do when we design a CP system, is we provide an even current distribution so that all areas can be protected. We also treat the outside and the inside of the tank separately. So, those are two separate systems. And we have to treat them entirely separately. Factors that come into play when designing a CP system. The size of your tank. You want to make sure that your anodes can distribute current through the entire submerged portion, or the portion that's in contact with the soil. If you have holes, opening, or valves, that has to be factored in. Also, pressure. Is it a pressure vessel? You need to take that into account. Perhaps your metallurgical bonds are going to have to be welds in this case, instead of bolts. You have to consider your material, your geometry, and the weight of your

anode. Also, what type of liquid do you have in your tank? Generally in Reclamation we deal with water. So that could be potable water, it could be water with heavy metals. But in some cases, you could deal with acids and bases and other liquids, sludge or any of that type of stuff. Also, you want to consider the resistivity of the liquid inside of your tank. Also, the resistivity of the soil outside of your tank. And temperature is also an important factor. So, because we split up the protection of our tank into exterior and interior portions, they are treated differently. Here I'm going to cover the exterior tank. Generally speaking, in Reclamation, we haven't had to protect the tank base with CP as often. There is a standard, the AWWA D100, which is a good reference for tank foundations. And that helps instruct in setting up your foundations. We'll use an oiled sand or clean sand with crushed limestone. The reason for this is because we're trying to increase the resistivity of the soil underneath the tank base. So, if you increase your resistivity, then your corrosion rate goes down. Same with increasing your pH. Then you're creating a situation in which it's not as likely that you'll need to have any cathodic protection in place. But once again, when you're dealing with your tank base, you have to make sure that your soil is evenly compacted so you don't generate those concentration cells, those oxygen concentration cells that I talked about earlier. In the image here, you can see some anode rings that are being put on the ground prior to backfill. In this case they are using cathodic protection in this image. And the tank, it will be sitting on top of this. So, when you use cathodic protection, you're using it in order to protect the tank base. You don't need to worry about the side, the external sides of the tank. That's not in contact with your soil. Anode rings are a potential configuration. Generally speaking, you want to add your permanent reference electrodes in this general area because you need to be able to monitor and test your CP system. So, the permanent reference electrode would be underneath the tank and allow you to do that. When dealing with the interior of your tank, you want to focus on your water quality. Sometimes your water quality is such that you may not need cathodic protection. You want to investigate—how are your water levels going to change? Is it significant? Will that affect what kind of a CP design you put in your tank? How accessible is your tank? Is it really hard to get in? Open tanks are much easier. And so you probably won't have the same limitations that a closed tank, or even a pressure vessel, would. You have to consider if you're dealing with potable waters. You want that AWWA—I'm sorry, that was a different standard. You want the NSF, ANSI standard, the 61. And that will help with determining a lot of your consideration for your potable water. Specifically, you do not want to use zinc anodes for this. Now, as I mentioned earlier, we don't often protect the tank base, but we often do protect the interiors of the tank. So, this is usually a much harsher situation. You've got water and you've got to deal with an electrolyte that you can't really change the resistivity of. And so having a cathodic protection system is often ideal. When dealing with the interior of a tank, you can have different types of anode configurations. You could have flush mounted. That would be the center picture. You could have anodes mounted either with a weld or bolts or something to the bottom of the tank. You could have string anodes, which you see in the left picture. And those essentially give you the distance requirement to go from the top to the bottom of the tank, but the string of anodes allow you to change the amount of current requirement based

on how much anode material you use. You can have flotation buoys, so that would be something you'll see on the right picture. And also ring mounting, which we'll discuss in the next slide. So, this particular slide is important because it is a design that we typically use, and we actually use it quite frequently. So, the idea behind this is that you use tension support cable to suspend your anodes in a circular ring pattern, primarily because your tank follows that shape. And you have an outer ring in this case. This image shows both an outer and an inner. You don't always have to have both. I mean, the design is flexible based on your needs. But here we have an outer ring of anodes. And I'm going to start using my mouse to show you some of the parts of this particular design. So these black dots represent your anode locations. So the ones on the outer ring are really long rod anodes, which in your side view they look—they're these tall portions that you see in the image. And the reason why this particular design is using the long solid rods is because the tank height, and trying to get current distribution from the top to bottom all along the tank wall. So, we follow the circular pattern in order to distribute them along the tank wall. And then the inner ring—because of the tank size, you're protecting the wall, but you haven't yet protected the base of your tank. So, the inner ring deals specifically with the bottom of the tank, in this particular portion, that the longer rods along your wall are not protecting. So, you can see them in your side view here. And they're concentrated in the center. And they're helping to protect the center of your tank. So, in general, let's see—these lines that look like spokes, here, they're your tension rods. So, you'll see they're acting to hold the anodes in place. They're held with a bracket, a support bracket, along the wall of the tank. And they're also held in place. There's a number of spots where you have the tension cables in this case. Let's see. Also, you'll notice these wavy, string-like lines. So, those are—What those represent are your anode connection cables. So, your anode has to be attached to your structure in order for you to have the complete corrosion cell. So, to do that, you would use a cable, with copper in this case, to attach that to your structure. Now, I mentioned before that you cannot—these are not load-bearing cables, so you cannot use them for any kind of support or suspension or weight hanging, anything. They have to be completely on their own. All they do is attach to the structure. So, typically in this portion of the drawing, the side view, those cables are running out of your tank and dropping down the side. We usually have a junction box there and that's where we do our testing, our cable testing. And there's also a weld that occurs inside your tanks. so you can have that structure connection with those connection cables. Keep in mind a configuration like this could also be done with flotation buoys, as well. So, doesn't always have to be long rods. We could also use string anodes instead of long rods. That would take care of that. Let's say you don't have the current requirements for solid rod, but you do have the height that you need to be able to protect the entire portion of your wall. That's what that would be for. Other features that need consideration when dealing with cathodic protection. Your isolation. So, typically isolation is performed across a joint or a flange on a pipeline that is leaving or entering your tank. The reason why we isolate is because we are trying to separate different systems. You'll reduce your cathodic protection current requirements by doing this. And instead of protecting more than just your structure, the isolation allows you only to worry about protection of the structure that you're intending to. This is also used to

disconnect dissimilar metals. You can isolate two dissimilar metals from each other so that they do not create a corrosion cell. You also want to make sure that when you're using the isolation, you're doing it in such a way to avoid interference between cathodic protection systems. Typically in a facility with a tank, there's yard piping, there's probably the exterior of the tank, the bottom of it, interior portion of the tank. They're all separate. And so you use isolation to make sure that you're not inadvertently connecting all the parts together. If you have a cathodic protection system on your yard piping, you don't want to be protecting your tank off of the same system because it's not designed to protect the tank as well. Same goes—you're protecting your tank, you don't want to be protecting the rest of your yard piping as well. So, the features that we generally look at for cathodic protection—or, isolated systems—would be all of your yard piping, any ladders that are present, risers, stairs. You also want to consider the wire rope, cables or whatnot that are used for the anode attachments. That ends up being part of the system to be protected and needs to be taken into account. So, the guidelines that we typically use are all NACE standards. And I have the three of them up here, and they're listed here for any further reference if you would like to look those up. Testing and inspection is going to be the final portion of this webinar that we're covering. So, when you're testing your tank interior cathodic protection system, they should be done at regular intervals or during any downtime. You want to check your polarized potential based on NACE criteria. You want to test the current at each anode in your junction box. We ran all the cables outside of the tank so it's easy to test and monitor them. This is what you would want to be testing. Want to check your rectifiers, make sure they're functioning, if you have an impressed current system. You want to examine how your—the condition of your coating, how that is performing. Do you have blisters? Do you have more defects? Do you have other issues that need to be addressed? What is the condition of your anodes? You can see in the images here, this is an ROV inspection of a magnesium anode that's sitting on the bottom of the tank floor. And so, it's being used to inspect the condition of the anode. And this is important to make sure that your CP system is functioning. Are all of your brackets still providing sufficient mechanical support? If you go inside of your tank and you find all your anodes sitting on the bottom when you had a rope support, that kind of tells you that there's some repair that needs to be done. Is that rope support functioning in all aspects that it needs to? Are all the anodes still where they need to be? Are all of your metallurgical bonds still intact? Do you have any corrosion in those or are any of them broken? And also, is the cable between the tank and the anode still electrically connected? Sometimes there are situations where this particular anode connection cable breaks, and then you no longer have your corrosion cell that your system is designed to have. And so that has to be repaired. So, when dealing with the NACE cathodic protection criteria, general rule of thumb is that you want to have a polarized potential of minus 850 millivolts with respect to a copper sulfate reference electrode, or more negative. This would be your instant OFF for structure-to-electrolyte potential. Or you can have a minimum of a 100 millivolt shift, and this would be compared to your native potential of your structure when it was first commissioned, when you first put it in service. And then you would be comparing, oh is it—do you still have a 100 millivolt shift? Also, Reclamation recommends

that you never exceed minus 1,100 millivolts because at that point you could start disbonding your coating. So, we use coatings on most of our structures, so this is an important criteria. Also, for more details regarding cathodic protection testing, you can reference the webinar. Jessica Torrey has access to that, and she can—I gave you her contact information earlier in the presentation. So, I would reference those webinars for more information on testing. Here I've shown an image of a copper/copper sulfate reference electrode. And that is typically the instrument that we use when we do our testing, this reference cell. Also, when dealing with your inspections, the frequency and how often they are done. We like to see them visually inspected when the structure is available due to dewatering or if it's up for maintenance. If—generally, we don't like to go more than five years if possible. You want to annually get your polarization potentials and your current outputs. Check your rectifier functionality, make sure that it's working in two-month intervals. And do a system inspection every three to five years. And this is our corrosion and coatings team. We have quite a number of us that focus on the coatings and the cathodic protection aspects to protecting our structures from corrosion. So, any number of us would be willing to answer any questions you have. And you can contact any of us for more information and get general questions answered.