Session 1 Transcript

GMI Biogas Subcommittee Training Series: Best Practices for Landfill and Organic Waste Management

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LYDIA STUBBS: Hi, everyone and thank you for joining. Before we start, let's go over some webinar software tips. First, there are two ways to connect with the audio today. You can either listen through your computer speakers or use the number that's posted in the webinar Q&A panel. We will be using two panels for today's webinar. The participant panel and the question-and-answer panel. Both of these panels can be found on the right-hand side of your screen. You may need to click the arrow next to the desired panel to expand and see all of the content. If for some reason one of the panels does not appear, navigate to the bottom right of your screen and click on the panels that you are missing. Live captioning is available for this event. To view or hide captions, click the closed caption panel on the lower hand side of your screen. You can then click on the arrow to select your preferred caption language. Throughout the duration of the webinar, you can enter questions into the Q&A panel. When submitting questions, please select all panelists from the dropdown menu before hitting send. This will ensure that all of the speakers see your questions. There will be an open discussion at the end of the webinar. During the open discussion, please raise your hand. We will call on you and unmute you. With that, I will pass it back to Patrick.

PATRICK COATARPETER: Thanks, Lydia. So with that, I'd like to first introduce myself and our panelists today. My name is Patrick CoatarPeter. I'm an environmental policy analyst with the Climate Change Division in the Office of Air and Radiation at the U.S. Environmental Protection Agency. My work supports the biogas sector at the Global Methane Initiative, where we're focused on reducing methane emissions from municipal solid waste management around the world. We have an exceptional panel of experts with us today. We're very lucky to be joined by Ms. Dana Blumberg, who's the vice president at SCS Engineers with 30 years of professional experience in civil and environmental engineering. For over 20 years, she supported the U.S. EPA's Landfill Methane Outreach Program and the Global Methane Initiative in many countries around the world. Dana will be our moderator for today's session. We also have with us, Mr. James Law, who's the vice president and senior geotechnical engineer at SCS Engineers. He also serves as the president of the International Solid Waste Association and as the chair of the working group on landfills and taskforce on closing dumpsites global initiative. Very, very happy to have Mr. Law with us today. We also have Mr. Bob Dick who joined SCS Engineers in 1990 and works on civil and environmental engineering projects related to solid waste management. Mr. Dick is the senior vice president responsible for leading SCS Engineering practice in the U.S., Mid Atlantic, and Northeast regions. And finally, we have Mr. Adedeji Fawole, who has over 30 years of experience in the solid waste industry and has been employed by SCS Engineers since 1995. Mr. Fawole serves as the senior project manager and the office manager in SCS Engineer's Columbia, Maryland satellite office. I want to sincerely thank our panelists and presenters today for being with us to share their passion and knowledge with us. You can find their complete bios in a document that was shared with all the registered participants, I believe, on Friday. Thank you very much again for our panelists. I'm just going to move to the next slide, please. And we'll do a quick overview of the Global Methane Initiative. The Global Methane Initiative or GMI was formed in 2004. So we're having our 20th anniversary this year, which is very exciting. GMI is an international public/private partnership focused on advancing cost-effective methane reduction projects and the recovery and use of methane as an energy source. We accomplish this mission by providing technical support from methane mitigation and methane energy projects around the world that enable our 49 partner countries to meet their methane reduction goals. Pakistan has been a partner country for over 15 years in the Global Methane Initiative, since 2008. And we're happy to be providing this training this week and look forward to potentially further opportunities for collaboration in the near future. GMI works in three key sectors. Biogas, which includes municipal solid waste, agriculture and wastewater, as well as coalmines and oil and gas. There's currently a lot of focus on methane for municipal solid waste around the world, and we would welcome any increased participation in collaboration with the government of Pakistan if you're interested. U.S. EPA is a founding member of the Global Methane Initiative. Provides in-kind support to develop tools and resources for GMI and serves as the secretariat for the Global Methane Initiative. So please feel free to reach out to me with any questions or desire to discuss the Global Methane Initiative further.

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Okay. Next slide, please. So without further ado, we have a great agenda planned for today. First I'll kick things off with a high-level introduction to methane and landfill gas. Then I'll pass it over to James to talk about dumpsites and dumpsite closure. And then Bob will discuss landfills and landfill gas systems. After that, we'll have a 15-minute open discussion led by Dana Blumberg where Dana will read the questions you put in the Q&A box for panelists to answer. You can also use your hand-raise function and we'll call on you to ask a question during that time as well. After discussion, Adedeji will present on the best practices for landfills and landfill gas operation and maintenance, economics of landfill gas systems, and case studies. And finally, Bob will talk about the tools and resources for facility operators. And we'll have another 15-minute open discussion at the end to answer any questions you might have. Next slide, please. Great. I'd like to start with a brief introduction on methane and landfill gas. Like carbon dioxide, methane is a greenhouse gas that traps heat in the atmosphere leading to an overall rise in temperature. Methane is considered a short-lived climate pollutant that only remains in the atmosphere for about 12 years, which is a much shorter time than carbon dioxide, which can remain for over a century. Methane being a short-lived climate pollutant means that cutting methane now is an opportunity to immediately slow the rate of climate change. Next slide, please. When organic waste decomposes in landfills and dumpsites in a low oxygen or anaerobic condition, it produces methane as well as carbon dioxide. And gas produced from the decomposition of organic materials in those anaerobic conditions is called landfill gas, which is approximately 50-55% methane and about 45-50% carbon dioxide, with trace non-methane organic compounds as well. The waste sector is the third largest source of global anthropogenic methane emissions, contributing about 12% of the total share. Pakistan's updated nationally determined contribution from 2021 estimates waste methane at about 19.2 million metric tons of CO2 equivalent in their profile. So there's some abatement opportunity there. I'm glad to be having that conversation and hope to continue it further. We know that capturing and using landfill gas as a source of clean energy is an opportunity to both reduce methane emissions, improve public health, and enhance energy security. That's all from me. I'm going to pass it over to James to talk about dumpsites and the need for dumpsite closure to cut methane emissions. Thanks very much. Take it away, James.

JAMES LAW: Hello, everybody. Good afternoon. Dumpsites and dumpsite closure is a topic dear to my heart, as you know. I'm involved with the ISWA and then we have a taskforce on closing dumpsites that was established back in 2017. And since then, we have several important publications regarding the roadmap for closing dumpsites as well as a case study that we use EPA, a new software called SWEET (Solid Waste Emissions Estimation Tool), that we use to estimate the greenhouse gas emissions. The project was funded by UN CCAC. I believe it's at the back of the reference later on when you get a copy of the presentation. Regarding dumpsites, it is, as you see in the pictures here, it is familiar pictures. If you have been to dumpsites, you would see all this. A vast area just covered with waste, which is not covered, and there's no daily cover used whatsoever. And a lot of times you'll see open fires burning. At the biggest sites you may see some slope failures, occasionally, because dumpsite by itself is not stable because it is unmanaged, uncontrolled mound of garbage. And there is no methane controls as well as there's no leachate management. The liquid coming out of the dumpsite is just flowing downstream. Next slide, please.

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So typically dumpsites, because it is an uncontrolled facility that is used by mainly municipalities in the developing countries particularly, there is a lack of security measures such as installing the security fence around the properties. So there's access to informal waste pickers and unauthorized people. The other features of dumpsites is that there are no liners at the bottom to prevent liquid or leaching from seeping through to the groundwater. So therefore groundwater would be contaminated when you have no liner system to contain it. You will see a lot of animals seeking for food at open dumps. I've been many times to India and they also have cows that feed on the trash at the dumpsites. It's created a lot of health issues when we consume let's say the milk from the cows, et cetera. It's not common that people do any compaction for dumpsites, so therefore the slopes, as you can see in the picture here, the slope is very unstable. And when it collapses, it will bury people at the foothill. Next slide, please. Uncontrolled dumpsite, it actually takes about 40% of the world waste, which is a huge component, as you can see. And it serves about three to four billion people worldwide. Back in

2014, ISWA identified 50 biggest dumpsites where it has direct impact to about 64 million people, people either living around it or working on a landfill as waste pickers. Dumpsites are estimated to generate about 10% of manmade greenhouse gas, which is by next year. So I think there was a slide, Patrick presented earlier for waste-related is about 12%. Next slide, please. This is a select example of historical dumpsite failures. You can see, for instance, 2000 the failure in Philippine that killed almost 300 people. And if you go down the list, 2017 in Ethiopia, there's 113 people killed. Now 2017 seems like a lot of activity. Not sure why, but three events at least listed here. East Delhi is the one that failed that killed two people. It's not a big slide, but nevertheless, it was a site that I visited several times. And this year, we have in Uganda that killed 35 people, which just happened several months ago. Next slide, please. So dumpsites are very dangerous manmade structures that is just like time bombs, you know. Anything can happen, depending on situations. Now, the reason why dumpsites need to be closed, as I say, contribute to 40% of the world waste volumes, which is a lot. So as I mentioned before, there is no liner system. So the risk of soil and water contamination is very high. It's almost unmanaged. So it may impact the drinking water for people living nearby, as well as anything that is related and consistent will be impacted. Methane emissions, just because there is no system to contain or control it, so it has direct threat to global climate change, as well as

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impacting local air quality because it has odor issues. Now regulatory necessities, most closure has to comply with the local and national standards. Of course, if you close a dumpsite, you need to follow some kind of standards. And this is so that we can close it properly and not further impact degradation of the environment and the health of the people living nearby. Next slide, please. So for landfill closures, to do it properly, you need to follow a systematic process of decommissioning it. One good reason is that we must ensure the safety and the health of the people working doing the construction. There are many options when we consider closing a dumpsite. The very first one is assuming that you have available land adjacent to the dumpsite. What I mean here by closing by upgrading into a controlled, sanitary landfill, which means you are closing the dumpsite next to an area where you can actually put in the liner systems to receive new waste. Or sometimes people put it on top of a dumpsite, but they provide a bottom liner system to contain the liquid coming out of the new waste. That is the first option. The second option is you can just close it as it is, putting an engineer cap over the waste. A lot of times it will require you to install lengthy gas collection systems so that you can collect the methane generated out of it for either flared off or if the quantity is big enough, you can use it for other purpose. That is you need to measure the sub-geometry allows you to put an engineered cap on top. If not, you have to do some work to flatten the side slope in order to be able to receive this cap, the new cap. Then the third option is—which I believe some countries like India they are trying to do something called bio mining. You basically literally remove waste from the dumpsite, flatten the ground as such. It's not an option for everybody because it does have a lot of thinking that you need to do, such as sorting material. Where does it go? And whether there's a market for it. There's a lot of issues dealing with the environment and the air quality all need to be monitored if you can take on a project. Next slide, please. Now, in terms of improvement that is needed for closing a dumpsite, planning. There are three topics there that I'd like to highlight. The first one is health protections. This sort of planning is almost like gearing towards the closing the dumpsite. But then also properly operate a sanitary landfill once you close the dumpsite. Because you need a transition time to do it. This will be the best time to train people how to operate sanitary landfills. Because certain components are identical. Health issues, we need to inspect all the incoming waste and record it, so that you know what is coming in. Second item on the bullet there is kind of important. We must stop open burnings. Through education and outreach programs, the communities need to buy into the idea of stop operating dumpsite and then moving to sanitary landfills. I mentioned earlier about security fence. That is important because you want to control people and animals going in and out of the dumpsite.

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And third is we have to address the social aspect of the dumpsite operation because we have informal waste pickers. And so it would be good to provide a designated work area for them so that they can pick the waste and not impact the other part of the dumpsite where you plan to close. And apply daily cover. Daily cover basically is about you apply about 16 cm of soil over any open area, open area that has waste surface. So those are important factors that need to happen. I'll move down to the environmental impacts, which waste normally is put in thin layers, which I think Adedeji is going to talk about that later on, so I won't cover that. Intermediate cover soil is applied to the inactive area and the side slope areas. So this is just to seal off any access to the animals, as well as control the leachate generations. And at some time you need to provide—if you're in an area during monsoon time, you need to provide temporary leachate management measures to control liquid going into the landfills. And also, if there is visible gas, you need to install a gas well and then flare it so that no methane is released to the atmosphere. And then the last item regarding the new system, when you operate a sanitary landfill, you kind of want it to separate the recyclable material at source. There is waste drain from the site. This is like I think there's a term called integrated solid waste management plan. If you go through that, then you can greatly reduce the amount of waste volume. A lot of activity that needs to be implemented, such as collection, transportation that needs to be established before you can start operating the sanitary landfills. Conservation is one of them. Next slide, please. Now, some chemical considerations. Obviously we need to choose the appropriate closure methods. And what I mean is depending on the slope geometry, like I mentioned before, and certain cap systems are more suitable for site-specific conditions. In the reference, I mentioned earlier that the roadmap for closing dumpsites, they have listed quite a few closure methods, as well as suitable cap systems. One other thing is I think most of the countries have regulatory requirements. You will be good to follow those regulatory requirements when you close dumpsites. And in terms of leachate and the methane gas management systems, it's depending on whether you wanted to do an active or passive system. And I think Bob is going to talk more about that. In terms of quality control and quality assurance program, this is very important because you can design all you want, but then during construction, if you don't have people monitoring it, control to make sure that the system is placed per design, then you don't really have a good system. Next slide. Challenges, there are many, but we listed four here. The first one is a lack of coherent policy and coordination. As you know, there are a lot of stakeholders, many stakeholders, and decision makers. And they need to work together so that they understand the purpose and why we close the dumpsites. So maybe if they understand that, then there is better coordination efforts there.

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Now, next is limited access to financial instruments and tools. I think this is fairly important because you certainly need to be financed if you don't have your own resources. Some of the banks, they can loan money to finance closure projects, so I think it's good to plan ahead of time, but then it may not be easy. And so it is one of the challenges most people face. Limited administrative capacity of waste authorities. As you all know, if you are from a certain part of the country, sometimes someone above you can overrule you. In terms of doing a closure project, it could be difficult in terms of administratively. And last item is the markets for recyclable material. This is always a struggle. As I mentioned before, if you are doing bio mining, such as you can see through all the stuff and then we have many different kind of piles. But then if there's no market for it or there is no incentive for doing that particular options of doing bio mining. Something to bear in mind, you need to find a market first before you start doing the work. Otherwise, you're going to end up with more than one dumpsite, but many piles somewhere else. Next slide, please. This is the very last slide. Just wanted to mention about closure care of a closed site. Now that you put the covered system down, a final cover system, which is capped, these things need to be inspected and monitored regularly because you want to evaluate the sediments and the erosion of the soil above it, during rainy seasons. And also the slope stability issue, vegetation cover, et cetera. So this needs to be monitored during the post-closure cares. In U.S. and most other countries, we have something called 30 years post-closure care as a requirement. Because then you need to monitor all these items to make sure that the cap is functioning properly. Somewhat runoff controls, these need to be managed. It's very important because, as you know, it can easily damage the cap system if you're not maintaining it. Finally, when you have leachate and methane gas control systems, they need to be operated properly, monitoring, and maintaining. Sometimes you also have groundwater monitoring wells along the perimeter of the sites. And it needs to be monitored as well, so that you know what's leaving the sites and what needs to be done more to control leachate and gas migrating off sites. And with that, I am finished with my presentation. Thank you.

BOB DICK: Thanks, James. Hello, everybody. I'm Bob Dick. I'm honored and privileged to speak to you today. I'm going to be presenting on landfills and landfill gas systems. And so

James did a great job of setting the background on the unfavorable conditions that are presented by open dumpsites. We all have a desire to close those dumpsites; however, because those open dumpsites are oftentimes the only means of waste disposal for an entire community or region, before closing them, we have to have some alternative and an engineered, modern sanitary landfill

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is a great alternative to open dumpsites. And the reason is because sanitary landfills, one, they're dependable and they're reliable. They work and function every day and in different types of weather conditions. They offer excellent environmental protection, if they are constructed, designed, and operated properly. And they're fairly low technology in terms of what's needed to operate a modern sanitary engineered landfill. Now, think of engineered sanitary landfills as more than just having a bottom liner system. And James explained the leachate collection system, the network of piping and drainage layers at the bottom of the waste that are used to collect and remove the leachate, which is contaminated liquid that has moved through the waste. In addition to that, sanitary landfilling involves spreading the waste in thin layers, compacting the waste, covering the waste, which contains the waste and prevents storm water infiltration. And so the sanitary land-filling is an entire process and engineered method. And globally only 8% of solid waste is managed in sanitary landfills. So I encourage you to think of engineered, modern sanitary landfills as an excellent alternative to the current conditions where open dumpsites are the only means of waste disposal. Next slide, please. A reminder of some of the key aspects of a sanitary landfill. Here we list several of the critical components and pieces of a modern engineered sanitary landfill. Of course, I've already mentioned there the second bullet from the bottom is the bottom liner system to prevent groundwater contamination. That's one of the key differentiators between an open dumpsite and a sanitary landfill is that impermeable, low permeability barrier layer liner system to prevent groundwater contamination. And then also a leachate collection system there. As I mentioned before, the waste is coming in and it's being placed and covered with daily cover soil material, and that's intentional. And so you're essentially building a structure with the waste. And then also, you have that compaction of the waste. The Landfill Gas Collection and Management Systems are critical. Number one, they reduce the methane emissions. They prevent offsite migration of methane through the subsurface soils that can be problematic because it can accumulate in structures, and methane is explosive at certain concentrations. So we're reducing fugitive methane emissions into the air. We're controlling potential offsite migration. And then of course it also reduces odors, which is key for a modern sanitary landfill. The stable slopes, James mentioned slope stability is critical and important, so there's no unintentional random movement of the waste. No open fires. And also no subsurface smoldering fires. And then we have security measures to stop the vectors, things like rats and birds that are undesirable and oftentimes the daily cover will do a significant work to prevent those. On the next slide, please, we have a graphic of a modern sanitary landfill to help you, for those of you that aren't in the business of waste disposal at a landfill every day. This graphic gives you some visualization of what I've talked about. Number one in the center there, you see the bottom liner system beneath the waste that contains it, and protects the environment and the groundwater.

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Number two, you can see immediately above that in the center, in the green color, intermediate and final cover. And so it's very important that as the waste is placed, we're covering it with a soil material. And then at the top, at the top when we're done and we've achieved final grades, then there's a final cover, oftentimes with a geo membrane plastic. Maybe some other geo synthetic materials for storm water interception. And then we have some gas extraction wells there on the bottom left. You see the arrows pointing to the gas wells that are drilled into the waste and remove and extract the gas. And then at the top, on the left, you see the gas header pipe. Header pipe is a slang term we use for the conveyance piping that conveys the gas from the waste over to the flare and landfill gas energy plant. And then finally, that leachate plant on the far right is used to treat any leachate that's extracted, any type of pretreatment before it's discharged to a wastewater treatment plant. So that gives you some idea of those main components. Next slide, please. So let's talk a little bit about landfill gas to energy projects and how those can be developed. I want to first start with reminding everybody that the landfill gas that's generated as the waste decomposes in the landfill, when it's collected, it can produce renewable energy. And the reason is, is because it contains methane. And that methane has the ability—it has inherent energy value to do useful work. And we can derive useful work from that energy through beneficial utilization of the landfill gas. And at the same time, it reduces the methane emissions, which is important. And we can produce various forms of energy. Electricity, heat, vehicle fuel. And so I'm going to take a minute here and we're going to outline five important points. We're going to talk about the basics of landfill gas collection systems so that everybody has a very basic understanding of what we're talking about to extract and harvest the gas and remove it from the landfill. I'm going to talk about how we estimate landfill emissions. We're going to talk about landfill gas modeling and that that modeling is a theoretical desktop computer model for trying to determine how much gas there is. And then I'm going to talk about these energy technology options. Those are the four points that I'm going to talk about here, in this order, and then I'll turn it over to my college, Adedeji, after we take a 15-minute question-and-answers break. And he'll address the economics of landfill gas systems. I hope that sounds okay to you. Next slide, please. So when we talk about a landfill gas collections system, it captures the methane and the other chemical compounds that are present in landfill gas that are generated and produced during the decomposition in landfills. And that decomposition is being produced—the gas is being produced biologically. So there's microbe colonies that decompose the waste and produce what we call landfill gas, a biogas, and that biogas typically has about 50% methane in it. And in the U.S., where I do most of my engineering work, we are required at certain landfills that are large enough, so if they exceed a certain design capacity, then they're required to install a landfill gas collection and control system.

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And right now, our regulations target non-methane organic compounds if they exceed this 34 megagrams per year emissions threshold. I want to talk about gas treatment. Sometimes the landfill gas, when we're using it for beneficial use, needs to be processed or treated to remove certain chemical compounds or constituents that are viewed as a contaminant. They're not favorable for purposes of doing useful work. So we want to remove those prior to beneficial utilization and energy recovery. Speaking of energy recovery, what that does is it essentially derives renewable energy from the landfill gas. So we think of landfill gas as a problem because it has methane emissions. I mentioned it can move outside of an open dumpsite or possibly even sanitary landfill if not controlled properly. And it can cause explosions to occur because methane is explosive at certain concentrations. And then of course it's a problem because it's malodorous. It has an offensive odor to it. And so what we want to do is solve those problems and achieve renewable energy from that. And then of course odor and safety management are extremely important. I just mentioned it controls the odors, reduces the risk of explosions, and reduces the pressure in that as well. Next slide, please. This has a few photographs that I hope, for those of you that aren't working in the solid waste industry, give you a sense of what these critical components of a gas collection are. So first let's start on the lower left where you see two photos. One is a horizontal well and one is a vertical well. These are the extraction components for the collectors that we install. They're made up of perforated pipe surrounded by stone. And those are put into the actual buried waste material. And when we apply a vacuum, we essentially suck out the gas that's being produced by the biological microbes that are synthesizing the waste. And so that's important to have the proper design and configuration of these wells. We call that the well field. Right above that, you see a picture called headers and laterals. Again, I mentioned earlier that headers and laterals are kind of an industry term that applies to the network of interconnection piping that conveys or transmits the gas from those wells to the blower flare station or a compressor station or a gas processing station, if we're doing a gas treatment. And then you see there in the middle of the page something called condensate sump. This landfill gas, like much biogas, it's heavily saturated and it's warm. And so we need to have a means by which to knock out the moisture. So as the landfill gas moves from out of the waste and through that piping, it's typically subjected to cooling. So it's a cooler temperature. And what that does is it knocks out and reduces the saturation concentration. And water accumulates. And we want to move that water out of it. We call that water condensate. And then finally on the bottom center there, you see a photo called flare. And that's where ultimately we're directing the gas to, if it's going to be combusted in a flare. And flares, in themselves don't produce any renewable energy, but they do destroy the methane and the odorous compounds within the gas. Oftentimes next to a blower flare station, we'll have some sort of energy recovery

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where we're either producing electricity or compressing the gas to route it to a boiler or other medium BTU (British thermal unit) use. Or possibly even creating renewable natural gas from it. Thank you. Next slide, please. So that gives you the background on what a landfill gas collection system is. I want to talk a little bit about how we estimate landfill emissions. I remind everybody here, when you're thinking of landfill gas, we use certain terms. One of them is how much gas is generated or produced. So when you hear about landfill gas being generated or produced, that's the total amount of gas that the landfill is making as those microbial colonies decompose the waste. Then that total generation or production of gas, it goes into one of two categories. One is, we collect it and we recover that. You saw that from those wells and the blower flare station and the piping there. If we can capture and extract that gas and now move it, then we can measure that directly using a flow meter. The thing that we can't always measure as easily is the remaining portion of the gas that is uncollected. Remember, we talk about gas generation or production. Then the two categories. Part of that is collected and part of it is uncollected. And if it's uncollected, we sometimes use the term fugitive emissions of that gas. And so for that uncollected portion that are fugitive emissions, we have two means by which we can estimate that. One is we can apply certain direct measurement techniques using surface emissions monitoring equipment or maybe drones or satellite that have optical gas imaging or tunable diode lasers can be used. But we're oftentimes only measuring concentration of the gas. And so it's difficult to convert that to what we call a mass flux or a flow rate of the emissions. And so that leaves us with another technique called landfill gas modeling, which is a theoretical desktop study. And so there is some uncertainty of that. But we often have, over the years of modern sanitary landfilling and landfill gas collection and control industry, we've adopted some good techniques on how to estimate how much gas is being emitted. Next slide, please. So just some more on landfill gas modeling. Some important factors to consider when assessing gas generation, again, I'll remind you what I just explained, is gas generation has both the collection and recovery part of it and so we can forecast the gas generation and how much of that gas we think we're going to collect or harvest and be in possession of. And then the remaining part of it, by doing the math, we can figure out how much is uncollected and escapes as fugitive emissions. Based on past and future waste disposal trends, we put that into the modeling. This is an important exercise because we estimate the recoverable landfill gas over a period of time. It's essential for decision making, especially as those of you that are in the financing of potential projects look at what is the return on any investments made for landfill gas energy projects. Some of the modeling tools I want to remind everybody that are out there, one is the U.S. EPA has a Landfill Gas Emissions Model. This is a first-order decay model that estimates gas generation. And then as I've explained, you can approximate or anticipate how much you'll collect, how much is fugitive. The SWEET Model,

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solid waste emissions estimation tool. This is really a programmatic system modeling to estimate how much greenhouse gas emissions will be produced when you make certain decisions about how you'll manage your waste. And then the IPCC (Intergovernmental Panel on Climate Change). This is probably one of the better known models for greenhouse gas emissions. And then the GMI Colombia Model. This is an example of a country-specific model for estimating landfill gas. And so it's been developed specifically for Colombia based on certain waste characteristics there. Next slide, please. Still sticking a little bit on landfill gas modeling here. I know I need to get to the energy part of it to explain that as well, but I just want to make sure that everybody understands that the landfill gas recovery, it's calculated essentially by taking the gas generation and multiplying by a collection efficiency. And that collection efficiency is a function of your design, how good your operation and maintenance practices are, and some of the landfill configurations such as cover integrity. Those factors affecting gas generation are your waste composition. So what is the actual waste material that's coming to the facility? Obviously if it's full of organic rich waste like food or paper, that leads to more gas, biogas production. We typically say that the more moisture content that's present in the landfill that increases the rate of gas production. So moisture content doesn’t necessarily make a certain waste produce more gas in total, but it makes it produce it faster. It accelerates the decomposition process. And then I point out that up to a point higher temperatures promote the microbial activity that I talked about and enhances gas generation. And so we have these methane generation and recovery estimating tools that can be for screening, for evaluating the viability of project development. For last thing on modeling, the next slide gives a graphic on how we're going to see the outcome. So if you could go to the next slide, please. This just gives what we call a gas generation and collection graph. Typically approximately 50 to 85% of the gas that's generated can be collected from an active landfill. And there's higher collection efficiencies, obviously if you have well-maintained systems. What you see there on the right in the graph is that we find that gas generation continues to increase over time with an active landfill, up to the point that the waste is no longer coming to the facility. So where you see the very top of the graph, kind of at an apex and a point, and it stops increasing and goes into a decline mode, that's typically when there is no more waste coming to the facility. Next slide, please. The last thing I'll be talking about is the energy technology options here. There's three fundamental categories of how we recover renewable energy from biogas such as landfill gas. I'll remind everybody, each one of these technology categories depends on the methane component in the landfill gas. It's the methane that has the ability to do useful work and produce different forms of energy. So when we talk about medium BTU, sometimes we call this direct gas utilization, it's called medium BTU because landfill gas has about 50% methane. So it has about half the value, the heat value, of natural gas, which is pure methane or typically almost 100% methane. So we call it medium BTU because you don’t have to do much processing or treatment of the gas. And you can use that gas as fuel in certain types of equipment

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like boilers, like furnaces. You can make heat for greenhouse and aggregate dryers. And then you can also use it to produce heat and evaporate your leachate. And so you can use one byproduct, the gas, as the form of energy to help you dispose of or one of the other byproducts at landfills is the leachate. A second category we talk about is renewable natural gas. When I started 35 years ago in the landfill gas business, we call this high BTU. And the reason it's called high BTU or RNG (renewable natural gas) is because you have to process the gas and remove the non-methane components and leave yourself with essentially just the methane component. And then it can be produced into a gas pipeline or compressed natural gas or LNG (liquefied natural gas) as perhaps an alternative vehicle fuel. The third category is electricity. And everybody understands this, of course. We take the landfill gas and put it into either internal combustion engines or gas turbines. And we generate electricity. And that electricity goes through what we call interconnect. And it's putting the electrons onto what we call the utility grid or the electric grid and transmitting those electrons as electricity to an end-user. Next slide, please. I'll wrap up here with just two or three more slides on these energy technologies, these categories. And remember, on the left here, we've talked about the collection system. In the middle, we talk about the processing of gas, either by controlling it just through combustion of a flare or some energy recovery options here on the right. And there you see, in the middle of the page, and lower on the page, the industrial institutional and arts and crafts usage. That's the first category I talked about, the medium BTU or the direct use. There in the center of it, right above the garbage truck, you see the second category I talked about, which we call either RNG or high BTU. That can either be injected into a pipeline or used as vehicle fuel. And up at the top where you see the power lines and the towers, that's the third category I talked about where we can generate electricity from the landfill gas. Next slide, please. So just a reminder that these landfill gas to energy projects have incredible benefits. Number one, you are destroying the methane component, as well as other undesirable organic compounds in the landfill gas. And that reduces odors. You offset the use of non-renewable resources. So you're producing a renewable energy form, therefore you don't need as much fossil fuel as your energy demands. And then here you have another source of income from the landfill. So in addition to accepting the waste, you're also able to generate revenue by selling the gas or selling the electricity or evaporating your leachate. And so you also have improved landfill conditions because you've reduced odors. You've reduced the pressure in the waste that can lead to offsite migration. And of course, you've reduced fugitive emissions. And there's a lot of potential benefits to the end-user. The whole idea from landfill gas to energy is that in theory they should be able to receive this fuel at a discounted price because it's coming from the landfill as opposed to some other source. And hopefully that enables the end-user to experience a cost savings. Next slide, please. We'll go into a little bit of depth here. When we talk about that medium BTU category, the direct gas utilization,

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you might ask, okay, well what types of things—what type of equipment can utilize the gas that way. It's boilers, kilns and furnaces. We've produced heat for greenhouse that you can grow vegetables or other plants in. I've mentioned the leachate evaporation. This is a fairly simple technology. Things like boilers have burner nozzles that can be retrofitted to use the medium

BTU gas. The end-user benefits from this low-cost fuel. The disadvantage is that you do need an energy user to be connected from the pipeline between the landfill and the user. So you need to have an industrial or commercial facility that has a need for the gas in fairly close vicinity to the landfill. Next slide. The second category I talked about, the high BTU or renewable natural gas, is when you upgrade the gas, you do have to process it and treat it to remove some of the chemical compounds in the gas that doesn't do any useful work. So we remove the carbon dioxide, the oxygen, and the nitrogen as well. And the advantages of course is this can be put into the pipeline or the vehicle fuel. And you typically have to have a fairly large landfill to do RNG. Next slide, please. The last category was electrical generation. This is the most prevalent type that we have here in the U.S. You combust the gas, either in a gas turbine or an internal combustion engine, and that produces electricity that can be sold through an interconnect either directly to your utility, maybe directly to a large customer nearby. And if you have a landfill that's part of another facility or near another facility, you can do what we call net metering, if the utility uses that. The average project size in the U.S. is about 4 megawatts. It requires about 10 cubic meters per minute of landfill gas at 50% methane to generate 1 megawatt. Some disadvantages are the capital and operational cost varies based on whether you're going to use a gas turbine or a large internal combustion engine. And then of course, one of the primary variables in terms of cost is the electrical interconnect components to put the electrons onto the wires. My last slide, the next slide here, there are challenges to landfill gas to energy projects. And we've listed a few of those here. One of them is when you're not achieving optimal landfill operations. So there's a lot of excess liquids in there or your waste isn't being compacted. Certainly, we have instances of insufficient design and installation from the engineer and installer. We've had, throughout the industry, some times where landfill gas systems just cannot be installed. They have to be maintained and operated. And clearly the contractual obligations with the partners, both the landfill owner, municipality, and whoever is doing the gas to energy project, if it's a different entity, have to be defined contractually. And so those are some of the important challenges that we've seen over about 40 years of landfill gas to energy project development here in the U.S. And with that, I'm done with this part on landfills and landfill gas. I'm going to turn it over to Dana to help us through a Q&A session. Thank you very much.

DANA BLUMBERG: Thank you, Bob. I have some great questions from the attendees. Starting with James. The first question, James, is can we get data of the total waste dumped on these dumpsites, which has had the slope failures.

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That might be something that you have to look up and get back to people. But I didn't know if you'd know that off your head.

JAMES LAW: No. I don't have the answer directly. Because dumpsites, as you know, what is coming in to the dumpsite, nobody measures it. So if there's a hole in the ground and then it's below ground, and even if you use modern technology like drum surveying, you can pick out the difference in the two surfaces between the years to come up with the volumes. But then go back to when the dumpsite started. There's amount below ground that you don't know what the volume is. I guess you can estimate it if you do some kind of fuel work. For instance, if you do borings to drill down to figure out how deep the waste is, and then you can approximate the volumes that way. But most of the dumpsites is just not—those data is not available.

DANA BLUMBERG: Thank you. The next question for you, James. Is there any way that we can minimize the effect of leachate on groundwater while closing the dumpsite?

JAMES LAW: I guess one common method, at least in the U.S., back in the eighties when the U.S. started closing a bunch of dumpsites, and one of the exercises there is to try to contain the leachate from migrating laterally off the properties. One thing we did is something we called barriers. Install barrier wall. You basically dig down in the ground and then put in Bentonite mix with soil, creating an impervious wall, in other words, zone, to contain the leachate from migrating offsite. And then you also install pump stations to try to pump the leachate off the ground for treatment. This is one way you can have some kind of assurance that leachate will not leave the site and contaminate the rest of the ground downstream from it. Because the one problem with dumpsites is always the same case. Because the bottom, you have no control. What goes straight down, goes straight down. And eventually, hopefully there is no direct connection with the groundwater systems. But if unfortunately it is connected, then there's not a whole lot you can do, other than try to minimize it.

DANA BLUMBERG: So once you put the final cover system in, does that reduce leachate?

JAMES LAW: Yes. It would reduce leachate. And then U.S. EPA has a model called HELP Model that can be used to estimate—whatever cover system you put down, it can be used to estimate how much leachate would generate from certain rainfall, let's say. But then what is in the dumpsite itself, it will come out slowly over time. But with a cap system installed, basically from that point on, you minimize rain water infiltrate through becoming leachate.

DANA BLUMBERG: Thank you.

JAMES LAW: And eventually it will trickle down over time. It would take many years though.

DANA BLUMBERG: Thank you. Another question is you mentioned dumpsite to control landfill conversion. How is this done as engineered landfill require a liner system? And how can we provide liners already in the dumpsite? I think you mentioned building a cell next to the dumpsite that would be—

JAMES LAW: Yeah. These are in between steps. While you're building a sanitary landfill elsewhere, and let's say your dumpsites still have areas that can be used temporarily as a control field—in other words, you install liner down to try to contain the leachate. And you can use it almost like a practice

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training ground for operating a sanitary landfill elsewhere. Because you don't want to continue to operate the dumpsites, but then you also need to use the dumpsite itself, adjust into it as the transition area. In other words, this is the in between step from dumpsite and sanitary landfills. Because you somehow need to improve your dumpsite operations so that you can get people trained in such a way that when they move over to sanitary landfill, they know how to do and how to operate the sanitary landfills. But the whole idea is to try to improve the environment and also the public health to a standard that is adaptable when you go to the sanitary landfill operations.

DANA BLUMBERG: Okay. This is a question that could either be Bob or James. What should be the preferred method of dumping waste in the sanitary landfill? Maybe this goes to Bob. In a baled system or loose form.

BOB DICK: Yeah. We typically see the vast majority, nearly all landfills operating in the United States, do not bale the waste. They're loose fill and then compacted by machinery compactors by running over the waste. We have, over the years, had some facilities try baling of the waste and then stacking the bales. Generally speaking, most operators eventually moved from that methodology to the loose filling with compaction.

DANA BLUMBERG: Thank you.

JAMES LAW: I want to add one point here. I think for the municipality, it should be very interesting, at least I try to share these opinions. Loose or compact, everything has to start with integrated solid waste management plans. In other words, if you can sort the waste at the source, meaning households, separate the recyclable material from non-recyclable material, and whatever is non-recyclable material goes to the landfill, if you can start from there, you can eliminate a lot of problems in between. And then you can really have control of the waste management system in your municipality. Because you have to start from somewhere. But a couple of weeks ago I read some news from Nigeria. The city of Lagos, they finally introduced a two-bin system. In other words, you put recyclable material in one bin and then the rest in another bin. I was hoping that they would do a three-bin system. In other words, why don't you also separate organics from the waste going into the landfill? Because then organics is a huge component in terms of methane emission reductions.

DANA BLUMBERG: Thank you, James. We're going to cover that tomorrow. So thank you for setting that up for us. One last question for Bob is separating the methane from carbon dioxide, at which stage would you do that or do you even do that?

BOB DICK: Yeah. There's three technologies that come to mind. In the old days, we used a lot of Selexol or Cryosol or absorption mechanisms. And so you might call that a wet wash, where you're essentially washing the landfill gas and seeing that the carbon dioxide is preferably absorbed. So it's a chemical absorption process. A lot of people now use membranes, and so the membrane is under high pressure. You just push the gas through a membrane, and because of the difference in molecule sizes between carbon dioxide and methane, then you remove and segregate, you separate methane from CO2, based on just sheer particle molecule size. And then there's temperature swing adsorption

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and pressure swing adsorption. Everybody has—as far as the second part of the question, which stage do you do that in after you typically removed all of the water through some sort of dehydration. So we oftentimes use glycol dehydration or other chillers. So you cool the gas down to near the dew point, typically around 40 degrees Fahrenheit. And then you remove that. Oftentimes it goes through some sort of a sulfur removal process, and then you have your CO2 stage, and then also your oxygen/nitrogen removal stage.

DANA BLUMBERG: But you would only need to do that if you were doing a high BTU project. If you were flaring or doing one of the other types of energy projects, you don't need to separate the carbon dioxide and the methane, correct?

BOB DICK: Correct. That's a great point, Dana. First of all, if you're not getting any beneficial energy recovery out of it, if you're just flaring the gas to destroy the methane and other undesirable constituents in the gas, then you don't need any processing like that. And also, if you're doing energy recovery through electricity generation or medium BTU, you can just leave the landfill gas as a mixture of those constituents. It's really only that high BTU or renewable natural gas when we're trying to create pipeline quality gas or vehicle fuel that you need to worry about removing the carbon dioxide. Thank you.

DANA BLUMBERG: Thank you. So we have other questions, but our time is getting away from us. So I'm going to save them for the end. And then anything that we aren't able to answer within our allotted time, we'll prepare some written answers for everyone. So I am going to move on. And Adedeji, you're up next. Thank you.

ADEDEJI FAWOLE: Thank you, Dana. Good afternoon, everybody. We've heard about dumpsites, how problematic they are. And then we heard from Bob about the gas portion of it. What I'm going to do is—so now that we have a sanitary landfill constructed, how do we best operate a sanitary landfill so we do not go back to the uncontrolled and dumpsite scenario? Today I'm going to talk about all these best practices for sanitary landfill operations from the moment the waste comes onto the site to the gas system and everything else that supports it. Next slide, please. Okay. So one of the first things is every sanitary landfill has a waste breach. This is where all customers come onto a landfill. The very first thing is checking to make sure that the waste coming in is acceptable to the site. One of the first things usually is they want to find out what types of waste a customer has. There are wastes that are prohibited from being accepted in a landfill, which is things like batteries and motor oils. Every landfill has designated areas where these things are placed. So, you want to direct customers that bring in waste that's not acceptable to a landfill space to a separate area. And these places are designated. Another key thing is posted signs. Every landfill here in the U.S. has signs at the entrance that list what's accepted and what is unaccepted. I think it's important for sanitary landfills to have that posted because customers coming in, they are able to see what they can bring in and what they cannot bring in. Oftentimes some sites will hand out flyers to customers on a regular basis which provides a listing of what they can bring to a landfill or what they cannot bring to a landfill. So we have good waste and we have bad waste. Usually, the better waste are the homogenous type that are easily handled. They are not damaging to the equipment at the working face. But they come in, in all—so at the weigh station, sometimes the attendant is not able to see every waste item that is brought in. So, it's by mere questions like what do you have in your vehicle. And sometimes there's what they call a random inspection where every so often a vehicle is pulled aside and a thorough inspection is performed to make sure that there's nothing that is prohibited that is going to the landfill.

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And then bulky waste, they are accepted, but sometimes they're difficult to handle. So there are ways to work those in the work face to make sure that they are handled properly. So, usually, what we do with the bulky waste is sometimes they are placed further inside the work face, now towards the outside slope just so they are handled properly. A good example of waste that are sometimes difficult to grade are mattresses. Mattresses and cushions, they tend to not compact. We all know that. But then when they're on the outside, they become a pathway for leachate outbreak. So, usually, at the work face you want to have the grading done in such a way that those type of bulky waste that are not compressible are pushed to the inside, and then they are covered over with good waste. Also, the landfill work face, what you have is what we call spotters. These are attendants that are putting eyes on the material as it's being disposed at the work face. The reason being that if someone brings in material that is prohibited and they get by the weigh station, those spotters are the perfect candidates to make sure that those things are immediately removed and are not allowed to be disposed at the work face. Next slide, please. So, placing waste at the work face, we want to be able to spread those in a manageable form such that it's easily handled before compaction. When a new sanitary landfill site is constructed, the very first layer of waste at the time is called fluff waste, soft waste, or select waste. They're typically from the residential collection areas. So, these waste do not have anything that can penetrate and damage the liner. We've heard from James and Bob how important it is to have that liner at the bottom, but that's what protects contamination of the groundwater. So we want to make sure that nothing that can puncture that liner is placed on that first lift. That first lift is typically about 120 cm. So that's placed. That's compacted with a dozer, not with a compactor because you don't want to push the waste too much. So, a bulldozer going over that, is sufficient to provide enough compaction of that first 120 cm waste. And then subsequent lifts can be up to 240 cm to grade. Usually once that's done, then the borders are grades. And then the compactor can now begin to be used to compact the waste. And landfill geometry is different, but usually you start to work from your lower portion of the landfill and then you work uphill. So working face control is important. There is standard area of measurement that you want to work with, but generally it's based on the traffic that's expected. So, a less busy landfill can have a smaller area to work with, and they can get vehicles in and out. You want to manage that work face because you want to be able to place your cover at the end of the day and not have a bigger area. And there are sites that are quite large and they do quite a good amount of traffic every day. Those sites usually work with a larger work face because they have long trailers coming in and they need to have room to kind of turn around and then back in and dump their waste. So, working from the bottom up, usually because you're pushing the waste, you try to minimize having a huge lump of waste. And then the borders are pushing it, it gets overwhelmed because it overworks the machine and then the waste begins to roll backwards down the bottom. So, we want to try and minimize the amount of waste that's been pushed to the final destination graded and then compacted. Next slide, please. So at the end of every day, all waste has to be covered. There's a reason for that. Obviously, as James had mentioned, you want to be able to control all the control vectors, and then having blowing later. Because sometimes waste, under windy conditions, you will have waste blowing everywhere. So, the idea is to create a manageable surface at the end of the day. Now talking about daily cover, usually about 15 cm minimum is sufficient to put over the waste at the end of the day to provide a closure for that day to not have your waste exposed to the elements. Usually, we don't want to use materials that create a low permeable condition. Generally, we try to keep

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clay materials away from being used because the more clay material is used, what that does is as your waste layers are built, you end up where as the leachate that's generated from decomposition of the waste is supposed to be vertically drawing into the waste below, once it hits that somehow impermeable layer, this is the condition that creates leachate wicking out on the side. Because now you have lateral movement of your leachate to the side. You want to keep that cover very minimal so it's not too thick. At the same time, use the best material that facilitates having that waste contact, and then having that leachate drainage down to the bottom. Weather conditions. Certainly, rain should not stop work face operations. So it's important that the landfill personnel have the ability and the resources to make sure that under all weather conditions, work face is accessible. Next slide, please. Leachate. We've heard about, obviously, sanitary landfills have a liner at the bottom. During that construction, network of piping is installed at the bottom. This is where landfill floor is sloped. So leachate is collected and goes to what is called the sump, the lowest part in the landfill cell. This is where leachate is collected. And then by use of pumps, it is moved from the landfill cell to a collection line outside of the landfill waste area to a processing facility that is contained. Inspection is probably one of the very most important things for a sanitary landfill. We are not just inspecting the active work face, but we're also inspecting areas that are inactive. As James mentioned, we want to make sure that you're checking for erosion. Over the years, the landfill will settle. When the landfill settles, you're going to start to have low spots in your landfill. Then that's going to create ponding. You want to avoid that liquid sitting there for an extended period of time to the point where it starts to drain into your waste. That is important to be checked. When that ponding or when that low spot is discovered, then it needs to be addressed immediately. Basically you go in there and you add additional soil. This is where the cover integrity is important to always be inspected. Erosion controls on the slopes is very important as well. Because as rain washes out the cover soil, you start to see your waste getting exposed. So when you transition from the active to inactive, then your soil covered thickness will change. So your minimum 15 cm for a daily cover, while you are actively filling an area, will now increase to 45 to 60 cm because now you're in an immediate condition where that area is not active. So in either case, you always want to inspect all of your areas regularly. And then sometimes, obviously when you have slope damage, you want to remove that or fix that as soon as possible. Vegetation mowing. That's very important because sometimes when the vegetation gets too tall, then it might hide erosion damages that are not visible to the eyes. So it's important to mow the slopes and the top area. Inspections will now reveal if there's any damage or any erosion that needs to be addressed. Also want to make sure that not mowing results in tall vegetation or trees growing. And those with model will penetrate the cover soil, and that's going to increase the infiltration of rainwater into the waste. Access roads. You can see from this picture, this is one of the key issues that most landfills usually have is providing all season access to the working face. It's a tedious process, but a landfill stays open, which means that the work surface conditions from the perimeter to the working face needs to be such that all customer vehicles, small or large, can have access to the work face. Some sites have a stockpile of asphalt millings, which helps to give access to traffic getting to the work face. The one issue that I've seen quite a bit is when you use those type of almost impermeable material to create an access for vehicles, inside an active field area, when you do not have that removed as your operations move to a different area, you've left that material in place—there's a landfill in the U.S. that has upwards of

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probably 10-20 meters of asphalt millings. And now they have to go back and pick that up because over the years that was left in place. And now they have to remove that because if that's not removed, what's going to happen is there's going to be a massive leachate outbreak because the leachate is not able to go down deeper into the waste mass. And it goes lateral and then creates a problem on the outside. So access road is very important to have for customers going in, and also landfill operation staff being mindful that anything that's constructed through the work face is removed before any waste is placed in that area. Next slide, please. So we talk about the landfill gas facilities. As Bob mentioned, and from the photos you saw, condensate is going to develop as the gas is moving through the pipeline to the flare station or going to the energy facility. And the idea behind those low points is to be able to drain that condensate away. Because sometimes when the condensate builds up and it's not collected, they often interview with gas flow. So you will have some lines, either by sediment of the landfill, where they create a low point in your pipeline, and then that needs to be investigated and then addressed. But the condensate is designed or the condensate draining is designed to the system to flow to low points where they can be collected. They are either drained back into the waste or they are in an area where they're actually pumped and removed. Blowers and compressors, those are components of our landfill gas processing systems. Blowers and compressors basically help to in a vacuum condition, pull the gas from the wells, down the header pipe, to the flare station. Blowers by themselves are typically enough for a flare. If all a landfill has is just a flare system, then the blowers are enough. But once you start to talk about creating electricity and having the electric system installed, then compressors are needed for high pressure gas use. Usually, these components are set basically near the flare station, not inside the landfill limits. The whole setup usually is outside of future field area because you don’t want to have to relocate those components again. Flare, just have to keep those maintained properly. As I mentioned earlier, if your lines are filled with liquid from the header lines, then you may have less gas flow to the flare station. So we have to keep those maintained as well. And then for the actual construction itself, I think it's important to document and to have some kind of oversight. Because what that does is it creates a nice build of the actual constructed condition. So in the event that some troubleshooting is needed or some line has to be opened up for service or repair, those records are accessible and they can provide information on where the lines are installed. Next slide, please. So what are the parameters to look for when you are designing and installed the landfill gas system? So generally, you go through a complete what we call landfill investigation. Because sometimes the way the landfill is built and operated, compaction rate and the waste types, they are all important to consider when you're designing landfill gas systems. If you have a landfill site that the waste is typically very, very wet, that could play a role in how the system is designed. If you have a site that is not well-compacted, those are things to look at when you're designing a landfill gas collection system. Local climate conditions also play a role. Sites in extremely cold or freezing conditions play a role. And then the humid areas as well shall also be considered. So, we look at both of those aspects when you're designing a landfill gas collection system. The collectors, usually obviously with not the intent of putting everything in is mainly to maintain emissions. So, we want to make sure that these wells are installed adequately over a coverage area. So, gas is collected and will minimize any potential methane emissions, as Bob has discussed in detail. Header piping. You saw the pictures from Bob's presentation. They can be either horizontal system or it can be vertical. All of them are intended to facilitate gas collection.

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The horizontal lines sometimes are installed in active areas because that basically ensures that they are not damaged as are not areas particularly active with waste disposal, but then those can be converted later on. But vertical wells, usually once you are about final grade, then those wells are dug or drilled into the waste. Next slide, please. So generally, when a well is installed in waste mass, there is a controlled system for each well. And all of these parameters we set in the first bullet are information that a gas meter that's used to check a well reading is providing. So you get the vacuum. You get the methane. You get oxygen, carbon dioxide, the—so all these items are actually recorded on a gas meter at each well location. And then the second one, pretty sure it's typical, landfill gas characteristics. Methane, oxygen. Usually, you're going to keep that less than 1% because the flare system, usually when it detects a high oxygen, then that's the reason that the system may have to shut down. So, generally, want to make sure that if the number begins to go up above 1%, then there's probably a situation where there may be a leak, may be a break in the system. And these are ways to kind of check if there's a problem in the lines. And then temperatures, suddenly you don't want the well to get too hot because then that becomes a problem with on the surface fire that you may not know. So temperature is one of the key components that's looked at during well monitoring. And then each site is different. So just have to adapt a design installation and monitoring to every individual site conditions. Next slide, please. So I'm going to move on and talk about the economics of landfill gas collection system. Next slide. The two tables on this slide are typical landfill gas collection and flaring estimates. And then the medium BTU system has some general typical costs here. These are self-explanatory. It shows us what we can assume the costs are. This is in the U.S. The costs will be different elsewhere because some local materials may be used. So it may vary in different countries. Next slide, please. And we're doing direct projects. We'll go from the micro turbine, the small power generation to the big ones, the 3 megawatts. These are the costs, which are inclusive of the generation equipment and the actual collection system itself. So again, these are U.S. costs from four years ago. And then if we're doing onsite clean natural gas for-use station, based on the different size of the inlet gas flow, here is the cost as well in the U.S. Again, this will be varied in different countries based on use and potential cost indications. Next slide, please. So when we're talking about economics, I think all of these are key items that are quite important. When we're looking to quantify what the capital cost will be and the operation and maintenance costs after a facility or a project is put in place. We go to the design and engineering, there's permit phasing involved. The site and the startup costs and admin costs. All of these also factor into when a facility is looking to engage in a gas collection system. These are costs that needs to be factored in and quantified before a project is started. Next slide, please. So when you're looking at economics and financing, there's a need to somehow estimate what the potential revenue will be because this factors into funding sources and also factors into what a facility expects. So whether it's from tipping fees or whether it's from sales, tax incentives—certainly, here in the U.S., there's quite a bit of good tax incentives to encourage

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beneficial gas use and collection systems. So different countries will have different ideas. But I think all of this needs to be put in play first to determine how viable a project for gas collection will be. Then you assess the economic performance of that looking at the values, looking at the rate of return, and the payback. And then, obviously, you factor in, from previous slide, all of the capital and the O&M costs. These are the steps that are very critical to assess the economic feasibility of backing a gas collection or gas generation project. Next slide, please. So once all of that feasibility is performed, then you kind of compare all of those options and then just to look at which one is the most viable there's something called sensitivity analysis. You have to perform that because sometimes some options may have a lot more non-price factors attached to it. Sometimes there's a risk to each option because it could be community buy-in. It could be government. It could be political. So, all of those things have to be—and developer may have their conditions as well that may make an option not viable. All of this has to be looked at in comparison. And then you go down and look at the financing options. Whether it's to a private banking system or investors or the federal government or international bodies. Municipals, here in the U.S., they are able to I guess issue bonds. That's one option that they have. I think by virtue of them being able to collect tipping fees, they are able to budget some of these projects into their operational budget for the year. So, they can draw from that. What that does is allows them to not all the time look for outside funding. I think that's something that may also be a positive thing. Because if you're able to collect tipping fees, you're able to factor in capital project into your budget. That way you are able to set aside funds for projects like gas work. Private banks, they also might be able to help on some low cost projects that they can fund, even if it's not fully actually. Next slide, please. Okay. With that, I'm going to go through a quick case study. Next slide. The city of Ahmedabad in India were looking to quantify how much natural gas they can recover from their dumpsite. So they wanted to see how much gas was available. On behalf of GMI, there was a pump test. Pump test is basically a series of vertical wells drilled into waste to measure—take some gas data. A work plan was put together and then they got some local forces to help with that. A driller was hired. Technicians locally were trained to collect the data for the test wells. And then a landfill model from that data collected, then a model was put together to estimate what the potential gas recovery will be. Unfortunately, the driller wasn't experienced in drilling into waste on a dumpsite. And then there were quite a bit of health and safety issues from that. And then the data collected, obviously, was not reliable enough to conduct the landfill gas recovery estimation. Next slide, please. Just a picture of the site. Sometimes I think this type of drill will be used drilling elsewhere. It's not the same that we want to use drilling to waste. Drilling to waste involves—remember, you're drilling through all kinds of material; bulky waste, incompressible waste. So usually you want something that can really puncture and penetrate all manner of waste. Unfortunately, the equipment that was used for this study did not meet the goal of intended operation. Next slide, please. So, since the drilling was not sufficient to drill into waste, but I think there was a learning experience for the driller because now I think

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he or she knows now what type of equipment is needed to really drill into waste. There were health and safety issues, obviously. I think one of the things that we stress on when we're working in landfills or dumpsites is health and safety, and having workers walking around in footwear that is not ideal for that condition certainly was an issue. When you're doing wells in waste, you don’t do excavation, usually. Because your drilling—when you have a very narrow diameter, you drill into waste. The moment you start to dig, it makes that well basically invalid because now you have to put the waste back in around the waste. And usually that's not how you construct any well to collect that data. Obviously, security was an issue because they had to guard the pipes and the blowers to prevent from being scavenged. And then technician was not actually experienced, so the data had a lot of errors in it. So quite a bit of unfortunate, what I call issues with this study. Next slide, please. What did we learn from this? Certainly, when you are doing drilling in waste, I think in the U.S. the luxury is that there are specified and specialized drillers that do drilling in waste. When you are doing the sort of pump test or any drilling in developing countries, it's important to have the right equipment for that. So, the driller in this case learned something about the specific materials and tools that will be needed to drill into waste. Health and safety, that's the number one goal. You cannot go wrong by making sure that everyone is safe when you're drilling a landfill. Even here in the U.S., it's stressed highly to make sure that everyone is safe, proper attire and proper protection put in place before any activity is performed on a landfill. Technician did the collector. Obviously, I think not having someone that's trained on site or enough on site was a problem. And I think more training is needed in the local level in terms of what type of information needs to be collected when you're doing a pump test. So, by virtue of that data not being reliable, the pump test was not accurate, so that potential estimation of gas recovery was not viable from that information that was collected. So, it was done basically with desktop model and that was how that was performed. I think that is all I have. Next slide. I think that's the end. Thank you. And with that, I'll pass it back to Bob to talk about tools and resources.

BOB DICK: Yes. Thanks, Adedeji. Appreciate that. And thank you to all of our attendees who have participated today. We are going to wrap up here with just a brief summary of tools and resources, and then have a question-and-answer period. In order to accommodate that, we're going to extend the webinar today until ten minutes after the hour. And so I believe local time that'll be 6:10 or on a 24-hour clock, 18:10, I believe, will be the time. We're just going to go for about another 16 minutes or so here. Next slide I'll go through about seven tools and resources. The first is the Landfill Gas Model. I consider this a gas generation, gas estimation, or gas collection estimate model. It was developed for the country of Colombia. But because Colombia has multiple representative climates, it's beneficial for basically anywhere. And then the next one is what we call the SWEET Model, the solid waste emissions estimation tool. I mentioned this previously. This is really a programmatic model. It has an output of air quality emissions. You're going to spend a lot of time on this in Session 4. But it's to make decisions about your overall solid waste management program, and then evaluate the emissions of methane, black carbon, GHGs (greenhouse gases). Next slide, please. The HELP (Hydrologic Evaluation of Landfill Performance) Model is a water-balance model. And it's used to estimate the amount of leachate

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that can be collected when you have a bottom-liner system. So it uses meteorological data to basically balance the amount of liquids that percolate through the waste and then can be recovered out of the bottom-liner system. Next slide, please. On this U.S. EPA Handbook here, the Best Practices for Solid Waste Management, the target audience is local municipal government authorities. It's more about the targeted for policymakers and agency staff. It does address what we've talked about today in terms of landfill gas generation and recovery. Again, although it was developed for Colombia, it's applicable anywhere. But it's kind of a big, high-level overview. And then the next one is the ISWA Operational Guideline. This one is actually for those of you attendees who manage or operate actual landfill facilities, open dumpsites. It's definitely targeted to transition from open dumpsite to sanitary landfills. But it's got a lot of practical guidance for management and operational issues. Next slide, please. And then the last two resources to cover, Roadmap for Closing Waste Dumpsites. It touches on what James talked about in terms of how do we go about closing open dumpsites and simultaneously developing an alternate option for proper waste management disposal. And the last one is ISWA, the Impact of Management Choices on Landfill Methane Emissions. This was an exercise that ISWA performed with representatives from all of the continents. So there was an Asia representative, an Africa representative, someone from South America, someone from North America. And we evaluated the different management strategies that could possibly be implemented at a facility. And then we compared and contrasted how that resulting greenhouse gas emissions compared with baseline. With that, I encourage everybody to dive deep into those different tools to help inform you. And I'll turn it over to Dana to moderate our final Q&A session.

DANA BLUMBERG: Thank you, Bob and Adedeji. We have a lot of good questions. Again, anything that we don’t get to, we will prepare written answer for you. The first question I think can go to Bob or Adedeji. As an economic point of view, is landfill gas utilization a financially sustainable model or environmentally friendly?

BOB DICK: Certainly. I think it's both. The answer is very much both. I feel that it is financially viable and feasible. The intent is to actually have landfill gas to energy projects pay off a profitable revenue stream. They are of course also environmentally beneficial and sustainable. Adedeji, would you agree?

ADEDEJI FAWOLE: Yes, Bob. I think your answers are correct, yes. I think they are both viable and environmentally friendly. Because you're going to destroy the methane. Most good-sized landfills have been candidates and examples of beneficial—have beneficial gas use. I think over the years and decades there has been quite good examples of those. So, yes.

DANA BLUMBERG: Thank you. The next question is another question about baled waste. Just seeing a couple questions on baled waste, I think that we can also provide some resources on the pros and cons to that. We can do that after the webinar in our written responses. But which would give more gas production, the baled dumping or the loose form of dumping? Considering that the organic content in both forms remains the same.

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BOB DICK: I'm going to try to clarify that when you have a one cubic meter of organic waste, you should get the same gas out of it, whether it's baled or loose, eventually over a very long time. But the question might be better answered which produces the gas faster. And I feel like the loose waste will generate the gas more quickly. And then it'll decline because the microbial colonies can digest the waste by accessing it more readily. When it's compacted in bales, I feel like the access to the inner baled parts will take longer. But the quantity should be the same over the life. But the loose waste will generate it faster.

DANA BLUMBERG: The next question is what's the permeability value of the cover material? Or is there a desired permeability?

ADEDEJI FAWOLE: For daily cover, no. For final cover, yes. You usually have a value for that. I think the reason why the daily cover is not qualified within the permeability is you want to continue to maintain that leachate drainage down to your collection system below. And any porous material is usually ideal. Now, there are sites that don’t use soil and they use some of these alternative covers like spray foam that basically does not require them to have anything to do. Just come in. And the next layer for the next day is in direct contact with the previous day's waste. I think using soil has its pluses and minuses. Obviously, some sites have an abundance of that and they use too much of those. And then you create a problem with not just gas collection issues later on, but then this leachate issue I talked about, if the soil is low permeable material like clay, then you don’t have that continuity in your waste layers. And then you start to have lateral leachate flow. So you want to have material as porous as possible, if you are putting daily covered soil. I'm not aware of any requirements to have a specific permeability for daily cover, no. For final cover, yes.

DANA BLUMBERG: Thank you. Another question is, is there any possibility of leachate going into the gas collection system. And then also—because it's between the waste. They were just wondering if, I guess the vacuum, if that can pull some of the leachate in.

BOB DICK: Yes. That is possible. We definitely see, in certain climates, the wetter climates, that the waste can become saturated. And that because you've installed those horizontal and vertical wells are ideal places for moisture to accumulate, that sometimes we need to pump the leachate out of our gas collection wells, both horizontal and vertical. So that is a possibility.

DANA BLUMBERG: Thank you. And then somebody was asking if you could provide the revenue generation from LFG (Landfill Gas) system to compare the economic viability of the project. I think what they're asking is the revenue would be the sale of electricity or the sale of the BTUs. I think that's how I'm going to interpret it.

ADEDEJI FAWOLE: Yes. That is correct.

DANA BLUMBERG: Okay. Also wanted to say that EPA does have a tool that we did not highlight. It is U.S.-based, but I think it could still be valuable. It's called LFG Cost. The purpose of that tool is to look at the economic viability of a landfill gas energy project. And then here's a question for Bob. Can we assume that the leachate will be—I'm sorry.

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There's so many good questions here. Can we assume that the leachate will be purified through the percolation if there's no membrane beneath it?

BOB DICK: Typically if the leachate is allowed to percolate into the groundwater and there's no membrane beneath it, then the leachate will contaminate groundwater sources. It doesn't just purify or treat itself or somehow remove the organic and other metals and semi volatile organic compounds. So I would say that it's very important to put that membrane there and try to prevent percolation. One additional answer to that is let's say you have, within a landfill, different layers of leachate from a zone that's higher up or lower. What we do see is that there is some reduction in the strength of the leachate as it filters through the waste. So typically our bottom-liner leachate is less of a concentrated strength than the upper zone. But again, I don't think you can rely that natural attenuation will just eventually purify the leachate in the groundwater itself.

DANA BLUMBERG: Thank you. Is there a specific composition of waste required for recovering or generation methane? Are waste primarily consistent of organic materials, various types of plastic, and other waste types. I think I want to add to this question. Organic diversion from the landfill, will that impact the methane production? Bob, you want to take that one?

BOB DICK: There's definitely the composition of waste to generate methane has to be something that the bugs, the microbial colonies and types of bacteria can actually eat. And they can eat things that have organic content like food waste, vegetative waste, paper, wood, anything with cellulous, hemicellulose, or lignin. You don't get methane or gas from what I call non-degradable or non-putrescible materials. Things like brick, concrete, asphalt, metal. So the more organic waste you have, the more organic material, likely the higher quantity of gas you're going to generate. As you state, Dana, as you divert organic material to something else, like an in vessel anaerobic digester or a compositing facility, then you won't have as much gas being generated in your landfill.

DANA BLUMBERG: Thank you. I think we need to wrap up there. I'm going to turn it—next slide. And I think I'm turning it back to Pat just final closing. Here's some references for you.

PATRICK COATARPETER: Great. Thank you so much. Thanks, Dana. Thanks to all of our presenters. This was such a wonderful presentation. Great discussion as well. Thanks to all the speakers and the presentations. Thanks also for the—you heard questions today from our attendees. Thank you for joining. If you have any follow-up questions, please shoot us an email at biogastoolkit@epa.gov. To help us improve the training, please fill out the feedback form that'll pop up on your screen as soon as this session ends. Also, we hope to see you tomorrow. We'll see you tomorrow morning our time, but 4:00 p.m. Pakistan Time. We'll have our second training session on methane mitigation through best practices, organic waste management. Thanks very much. Thank you again to our speakers and to all the attendees. We'll see you all tomorrow.

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