Session 2 Transcript

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

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PATRICK COATARPETER: Thank you for joining the second training in the Best Practices for Landfill Management and Organic Waste Management series. This training is hosted by the US EPA on behalf of the Global Methane Initiative and the Asian Development Bank. It will be delivered by the EPA, SCS Engineers, and Abt Global who have extensive knowledge in solid waste management and biogas project development. Today's training session offers an in-depth look at various organic waste management treatment options, including anaerobic digestion, composting, and emerging trends with a focus on black soldier fly technology to reduce methane emissions. Before we get started, I'll pass it over to Beleil Lamb to walk us through how to work with WebEx today.

BELEIL LAMB: Hello everyone, and thank you for joining. Thank you, Patrick. Before we start, I want to go over a few 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 posted in the webinar Q&A panel to your right, and then 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 see all of the content. If for some reason one of the panels does not appear, you can navigate to the bottom right of your screen and click on the panels you are missing. Live captioning is available for this event. To view or hide captions, click the closed caption button on the lower left-hand side of your screen. You can then click the arrow to select your preferred caption language. And throughout the duration of the webinar, you can enter questions into the Q&A panel. And when submitting questions, please select "all panelists" from the drop-down menu before hitting "send." This will ensure that all of the speakers will see your question. There will also 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. And with that, I'll pass it back to Patrick.

PATRICK COATARPETER: Great. Thanks very much, Beleil. I'll introduce myself first and then I'll walk through our panelists today. We've got a great series of speakers, but first, my name is Patrick CoatarPeter, and I'm an environmental policy analyst with the Climate Change Division in the Office of Air and Radiation at the US Environmental Protection Agency. My work supports the biogas sector at the Global Methane Initiative, with a focus on reducing methane emissions from municipal solid waste management around the world. We have an exceptional panel of speakers with us today, just as yesterday. Again, we have Ms. Dana Blumberg, who's the vice president at SCS Engineers with 30 years of experience in civil and environmental engineering, and for over 20 of those years, she's supported US EPA's Landfill Methane Outreach Program and the Global Methane Initiative in many countries around the world, and Dana is going to be our moderator again today. We also have Mr. Erik Anderson, who's a senior consultant with SCS Engineers in Long Beach, California. He has 14 years of energy experience – or engineering experience, excuse me, and process design experience as well in the renewable fuels sector, working on projects from concept development through front-end engineering, design, and construction management, so a whole range of experience. We also have Doctor Hussain Ali, who's a staff professional with SCS Engineers in Richmond, Virginia. He earned a PhD in civil engineering from the University of Texas at Arlington, and has been actively involved in various projects related to life cycle analysis, methane emissions and environmental policy development. Very, very happy to have this great panel of speakers with us today, and very much looking forward to what I hope is a great conversation. You can find the complete bios of our presenters in a document that was shared with all registered attendees. Next slide, please. Great, so we have an excellent agenda planned for today. First, we're going to provide a high-level introduction to organic waste, then Erik will talk about anaerobic digestion, its role in waste management and methane mitigation challenges, limitations, and keys to success. After that, we'll have a 15-minute open discussion led by Dana Blumberg where Dana will read your questions that you put in the Q&A box for panelists to answer. I do want to note, you can also feel free to raise your hand during this time and ask a question. We'll unmute you, and you can – the floor will be yours. We had some great questions yesterday, and I thought it was wonderful. But if folks want to ask questions in the Q&A, you're more than welcome to do that. So after the 15-minute Q&A, after the discussion, Hussain will present a presentation on the basics, the challenges, the best practices and limitations of composting, and Hussain will also present on the emerging trends in organic waste management, particularly focusing on black soldier fly.

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And then we'll go back to Erik, where he'll talk about value added products from organic waste treatment projects. And then finally, we'll end with another 15-minute open discussion at the end to answer any questions you may have and hopefully tee us up for tomorrow as well. So thank you very much again for being with us this morning. Looking forward to a great presentation and lots of great questions and discussion, so thank you – or this afternoon, sorry.

ERIK ANDERSON: Thank you. Patrick, can you hear me? Sounds good. As Patrick mentioned, my name is Erik Anderson, and I'm here to talk with you at the beginning of the day first about an introduction into organic waste, organic waste management, and then into anaerobic digestion, one of the common, very popular methods for organic destruction and energy recovery. So with that, I'll go into the introduction of organic waste, the importance of organic waste management. Organic waste we should define right now are any organic material, biogenic carbon, organic material that's produced in a biogenic carbon cycle, which is things grown in real time, taken in years, not millions of years to form. And this is what – organic waste is generated from everyday use, industrial, and commercial production. In the waste sector, methane can be produced due to the decomposition of organic material, this material is specifically. Pakistan currently generates around 68% of its waste from organic material. This provides an opportunity to collect the material, convert it to methane, and use it for renewable energy. Management of the organic waste to produce useful bio products like biogas, compost, etc. instead of traditional disposal in landfills or dumpsters. Controlled disposal, as we'll talk about, like in anaerobic digestion or compost, can yield a high efficient process to create a bio product, along with the most efficient way to collect the energy stored in the methane. And right here, you can see the kind of graph of current waste emissions globally by methane, by sector, the largest being agricultural here in the green. Second to that is energy production. Then that 12 down to waste, seven wastewater, and then one for other industrial processes. Next slide, please. An introduction to organic waste. By definition, organic waste refers to any biodegradable material from plants and animals. So again, from plants and animals that are grown in real time over a span of years, not a product that comes from buried within the earth that took millions of years to form. That's the distinction between biogenic carbon and non-biogenic carbon, carbon that is in a short-span life cycle compared to one that takes millions of years. So we are interested in the organic waste that was produced years ago, not petroleum waste dumped in the ground. Sources, as we said, are food waste, yard trimmings, crop residues, paper and pulp, and any manner of industrial and commercial organic waste that comes from food processing industries or possibly animal processing facilities, excuse me. Environmental impact, decomposes and contributes to methane emissions. So, incorrectly done, pile into a landfill, these will create methane by natural decomposition without the presence of oxygen. This will create methane and it will fall into the atmosphere. To do this in a controlled environment where you can control the outputs of the gas, whether that's methane to be burned for energy, or CO2, is a more efficient process to actually engineer and control the system, rather than just letting it go to landfill. So, next slide, please. Organic waste management challenges. So, there's hurdles with any process, any project that comes into play, and organics collection management is no different. The first one is collecting and separating at the source. This is most common in municipal and city centers where you're trying to involve all citizens at the collection site. So, it's up to the individual to separate their organic material from their non-organic material, their recyclables. This is a challenge only because not everybody likes to operate and perform to the same standard. So when it's left up to the citizens, there's a lot of potential for contamination, then we move onto the second component, preventing contamination with non-organic waste. So, all of these waste management technologies and techniques that we're using are all prone to failure by contamination, whether that's at the site,

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separating it from the consumer or it's from people incorrectly, not intentionally, recycling the wrong materials, sending it through the wrong pathways. But all of these end up in the technology themselves, whether it's anaerobic digestion or composting, and they can all be detrimental. In a best-case scenario, they get passed through the process inertly and they don't affect it too much. In a worst case scenario, they can have detrimental effects to, say, anaerobic digestion or composting. So again, one of the largest challenges in waste management is just the purity and the consistency of the incoming material. Next one of the challenges is balancing the nutrients. Waste management relies heavily on bacterial involvement, whether it's anaerobic digestion for methane production or it's composting and using aerobic bacteria. Both rely on a system of biological organisms. And to that degree, you need to feed them the right profile of materials, and that's balancing the nutrient in materials. So, a lot of times, the waste material is not built or structured to be the most nutrient-providing for an organism. So sometimes, those need to be offset, or monitored, or engineered to a degree that you're going to be reaching high performance from the bacteria. The next major challenge, another one is odors and managing the leachate. These systems, specifically landfills or anaerobic digesters, they can be very odor-producing because the material itself, whether it's animal byproducts, manure, or food waste, the technology and process itself actually controls odors by destroying the volatile organic compounds involved. So, you're taking these volatile organics, converting them into methane, and burning that in a controlled environment. Same with leachate. It all becomes part of the operation and has considerations to clean up the water that's produced during the process, rather than in a landfill where this stuff can go out and potentially be hazardous to the environment. Producing high-quality byproducts, another major challenge. Not all composting or anaerobic digestion systems are the same, and they're very highly dependent on the material going into them. So, each project is different and can come with its own challenges on the backside. Sourcing of clean feedstock, just like the collecting separation at the beginning of source, contaminating is a big issue and consistency of a quality feedstock are all major challenges. And the last one is marketing the end products. As I said, all projects are different and all end products are different. So, a quality and complete understanding of the profile and composition of that end product, and having a good understanding of its value in the marketplace are all major challenges to developing a sound waste management program. So from there, we'll move on to – here's kind of a scale, an infographic, if you will, of the easiest and most basic ways to approach waste management. And on the left side, the easiest one is just to reduce, prevent wasted foods by using less, buying less, and serving only what is needed. This is similar to the recycling infographic of reduce, reuse, recycle, where the most appropriate measure is always to use less, buy less, and make less. Barring that, the next appropriate measure would be to donate and upcycle, so to reuse, the second arrow in the recycling triangle. The next would be the actual use and the reuse of the material as a second stage, or as a second-stage use. So no longer its primary use as a food waste or a material byproduct. It now goes into animal feed or left unharvested in the field, so it can leave its nutrient value on the field for growing next year, and then moving that into a function like composting or anaerobic digestion for energy recovery. And then at the very end of it is sending it down the drain or incinerating them to a landfill. So, those are the ones we want to avoid if we can use it for a higher value product upfront. Next slide, please. All right. And with that, we are moving into anaerobic digestion. So anaerobic digestion is one of the key tools for waste management, specifically where industrial and water

– food processes are involved that have waste water discharging from their facilities. We'll go into all the different examples here. So next slide, please. Thanks. So, introduction to anaerobic digesters. On the right here, you can see a picture of a fairly typical anaerobic digester. As you can tell, these are just tanks. They're tanks that have certain degrees of mixing, and agitation, and engineered flow rates, but they're all sourced to do the same

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function, which is to break down organic materials in the absence of oxygen. Anaerobic means without oxygen. So, unlike composting, which uses air to break down the material into CO2, primarily, in the absence of oxygen, you get methane and CO2. Organic waste is converted into biogas, usually around 50% methane to 50% CO2, although with different substrates that are rich in protein, and fats, and oils, that methane concentration can go up into the 70%, with CO2 only being 30% of it. So, 50% is fairly on the low end, but this was used and collected post-anaerobic digestion to create energy through thermal heat or through electricity. This can reduce landfill usage and methane emissions. Examples of waste that can be degraded anaerobically are food waste, yard waste, byproducts from industrial, or commercial land, or – sorry, yard cleanings, trimmings, grass clippings, paper waste, agricultural waste, animal manure. Animal manure is a very large market for anaerobic digestion and it's been a big part of manure management systems here in the US for many years. Along with that, fats, oils, and grease, also known as FOG here in the US is a big market as it relates to water treatment systems. Fats, oils, and grease can be separated and purified during water treatment and usually don't have a high value-added market to be fed into outside of animal feeds and other reuse products, so they're a very ideal substrate for bleeding into anaerobic digestion systems because they're very rich in energy density. Excuse me. Lastly, I have here water treatment sludges. That's a very large industry in the municipal city-driven water treatment cleanup efforts. So, wastewater treatment plants will often incorporate anaerobic digestion on site as a means of passive organic destruction. You can reduce your organic load by up to 70% to 80% through an anaerobic digester, just converting your organic mass into methane and CO2, which again then can be used for energy. Next slide, please. The environmental benefits of anaerobic digestion. The obvious is the reduction in methane and GHG (greenhouse gas) emissions to the atmosphere. If this material was not to go to anaerobic digestion and it was going to landfill, it would be sent to a pit and buried just like anaerobic digestion, it would be without oxygen. The material inside would slowly convert to methane and CO2 and be released into the atmosphere without any system to cover it and collect it. So, by doing anaerobic digestion, you're controlling the environment. You're encapsulating all the biogas that comes off, and again, you're able to funnel that through boilers or turbines to generate energy or electricity. In the example of landfills – and organics can be separated from the MSW, the municipal solid waste, and processed through anaerobic digesters to make landfills themselves more efficient by pairing them up with a liquid treatment system like anaerobic digestion. Energy production, obviously, as we talked, anaerobic digesters produce biogas, which can be converted to electricity and heat, promoting energy sustainability. Waste reduction, as I mentioned, the material being fed into a digester can be reduced by volume from 70% to 80%. You're converting the organic, rich, soluble material in there, destroying large macromolecules, and overall reducing the volume of the material being processed, which is one of the largest benefits for considering anaerobic digestion. Manure management reduces methane emissions from manure lagoons, minimizes odors and pathogens. These are large pluses for large farms, lots of manure. If you have a manure management system that incorporates AD (anaerobic digestion) use, it includes a manure collection system. Facilities are – the odor improves because you're collecting and mitigating the odor in a centralized location before it goes into AD for collection. You can reduce pathogen spreading issues. So, AD has been a tool of manure management for many years. Lastly, one of the major benefits, soil benefits, from the final byproducts. After anaerobic digestion is done, you're left with two components, a liquid phase and a solid phase of residual organic material, which is very rich in nutrients and can serve as an effective organic fertilizer and soil amendment, and in certain markets has a very value-added

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component to it and will affect the economics of anaerobic digestion on the sale. Next slide, please. So here, we have an infographic of a general anaerobic digester in the middle, showing all the different feed substrates at the top end and all the different uses for it at the bottom end. And you can see on the top end manure, you've got wastewater biosolids. These are solids that have been condensed during the water treatment mechanism, collected and concentrated during water treatment during the early clarification stages. And they're ideal, they're very fat-rich, very protein-rich materials. They make a decent amount of biogas and they significantly reduce the volume treated at water treatment facilities. Second is food waste. This can be industrial or commercial food waste. It can be residential. But as mentioned on the residential side, there is more prone to contamination from the individual. You'd rather streamline your material from a single source, coming from an industrial facility where you have consistency over your product or your incoming material. The other, the last bucket is the energy crops – fats, oils, grease, crop residues. Energy crops in Europe are very popular for supplementing a lot of co-digestion. So, if you have manure, they will supplement it with energy crops for its carbon content to improve the biochemistry. But really, any of the materials can all be co-digested together, and one thing of note that's important is most systems that do co-digestion will want to incorporate a manure component to it. And the reason for that is manure, by its own nature, is loaded with bacteria, these same anaerobic bacteria that you'd find in a digester. So, any system that is co-digested with manure has a natural inoculum to it added every day as just a function of adding fresh manure to it, whereas systems that are co-digested without any manure to them rely solely on the population within the digester. And if things, if they are fed material they don't like, or if there's toxicity issues, they need to recover – they tend to recover a little bit slower than systems that have the manure coming in it fresh every day. But you can see from the digesters with a degree of processing. On the left, you can take the biogas, clean it up, and convert it to any number of useful products. Bioproducts can be formed in the laboratory, and plastics at some expense in processing, but it can be done and has been shown doable. More commonly, electricity and heat seem to be the more economic models that people have developed, vehicle fuel as well, CNG, and then renewable natural gas is also a very common energy production method as being incentivized here in the US. On the bio product side of it, you've got your digestate. Digestate is the term for all of the material leaving the digester, and that can be looked at as liquid and the solid phase with some separation technology. Those can both be used independently or together. The most common one is as an organic fertilizer or soil amendment for that solids material. It's very rich in nutrients. All of the nutrients I should say going into an anaerobic digester essentially come out in the same state. They're not oxidized. They're not formed, reformed in a way that makes them less useful. They're essentially whatever the nutrient level you put into it, you can regain on the back end as a fertilizer. The bacteria will incorporate the metals into their chemistry, but essentially, they leave within the bacterial mass as well. So, you'll get the same ratios of NPK roughly leaving the system that you will have feeding it. Along with the fertilizer, there is an animal bedding that's a very popular product in the anaerobic digestion of cow manure. So, especially large dairy barns that use hay and straw as animal bedding, it's very high in fiber. The material does not break down very readily in anaerobic digesters, so at the back end, once the water is removed, it's slightly dried, the material makes an ideal cow bedding. Other products, building materials, crop irrigations for the leachates are all been proven very effective land management and manure management tools for farmers. Next slide, please. So, here shows – this slide shows the different stages of anaerobic digestion. And the important takeaway here I think is to understand that all of these reactions happen simultaneously inside one vessel. So, the material comes in and

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the material, most generally, materials can be broken up into three large categories – four: that's carbohydrates, proteins, fats and oils, and inert material. Inert, meaning it goes through the process unchanged, the same form it goes in at, it comes out at. It doesn't produce or contribute to any of the biogas. It doesn't break down as part of the process. But unlike the inert material, the carbs, proteins and fats do break down and they break down in a very well understood manner that starts with hydrolysis. Hydrolysis is the first stage, and it just means breaking down the larger chain of molecules into smaller chains. So, instead of large proteins made up of chain links of amino acids, the chemicals will break down these into individual amino acids, like same with carbohydrates. They will break these into the monomer single units that form up these large chains of systems, oils as well. The smaller bits, once they're broken down, move into acetogenesis. In this stage, all these organic molecules are converted into organic alcohols and acids. As you'd imagine, it's kind of the souring of food, rancidity. This is the fermentation stage where you're producing alcohols and acids from these larger molecules. These alcohols and acids then move into acetogenesis, converting these low-weight carboxylic acids and alcohols into acetic acid, the primary precursor for methane formation. That is done in the last stage. Methanogenesis, performed by methanogens, take the acetic acid portion that's been now formed by multiple different pathways and converts that into methane and CO2. It should be noted that the last stage in the process is also the most finicky. Most of the parameters around anaerobic digestion and operations are aimed at trying to keep the methanogens happy. They're the slowest growing, they take the longest to propagate, and they are your money makers, essentially, and you need to do everything needed to keep them happy. But again, the biggest takeaway here is all these reactions happen simultaneously in one vessel. So there's many intermediate products at one stage, things being formed as they're being eaten up at later stages. So, it is a large mixture of multiple different pathways and reactions happening simultaneously and can be difficult to interpret sometimes from single snapshots from analytical testing, but... Next slide, please. So, factors affecting production of methane. Although there's many factors that affect methane production, operationally speaking, there are ones that the teams will focus on for control of the system. Factors affecting the amount of methane produced, waste composition, percentage of organic waste. Another way to say this is the total solids content and the volatile solid content of the feed you're going – that you're sending to your anaerobic digester. The biggest components to any feed are whether it's moisture levels, and by that, I mean how much water is in it. The other one is how much total solids, and the third is volatile solids. And the difference between the total solids and the volatile solids is inert material. So, everything that would go in and come out without any effection, without any change, it's the volatile solid component that we're actually interested in. This is the material that is actually being converted to methane, and in early projection models and due diligence work, this would be the amount, the material of concern for predicting your methane production and potential. The other large factor affecting production is your organic loading rate, essentially, a measure of your organic compound component entering the AD reactor. In the US, a lot of times, it's measured in pounds of volatile solids, the material we just discussed above per cubic meter of AD each day. So again, it's a density load, it's organic density loading rate to your reactor, and there's ranges. If your organic density is too high, you can starve your system, your kinetic movement goes down, and performance ultimately goes down. If your organic loading rate is too low, there won't be enough bacterial population in the reactor itself that you're prone to events called wash outs, where there's so much influx of material coming out that your bacterial population can't maintain itself, and you essentially wash out all of your active bacteria. Another large factor affecting the rate of methane production is temperature. We'll show in another slide here, but there's two temperature ranges that are really critical for methane production. That's mesophilic and thermophilic.

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And on graphs, you'll see that there's a large performance difference both to the left and right of those temperatures, but also between. So, there's kind of a performance valley due to the activation enzyme and its ideal temperature range. Another large factor affecting methane production is grain size or particle size and material. Large particles that move into an anaerobic digester that don't expose the interiors of them essentially need to be hydrolyzed from the surface area of the outside in. If you can break that material down almost to a suspended or soluble state, anaerobic digestion can happen that much quicker, cutting down on the amount of time it takes to degrade the material. Next slide, please. Factors affecting viability of microorganisms. Like viability or methane production, these overlap quite a bit, but impact on methane production, as I mentioned, there's two temperature ranges: mesophilic and thermophilic. And if you were to plot these out, there's a clear performance dip between those two temperatures, and that's a result of the ideal temperature range of certain activation enzymes produced by these bacteria to the left and right of them, so you really want to be as tight to those two temperature ranges as possible. Thermophilic would come up if you had a two-stage anaerobic digestion system. Sometimes, rather than having a single tank with all the reactions going on simultaneously, they will break it into two tanks, controlling pH and temperature to force one tank to be more thermophilic and one more mesophilic. And there are benefits to that system as well that we won't cover in this discussion, but know that they are out there. Excuse me. pH, another critical factor for controlling viability of the microorganisms. Acetogens prefer lower pHs relative to 7, at 5.5 to 6.5. Methanogens prefer higher temperatures. Another reason why above, you might break it into a two-state system, mesophilic and thermophilic. You can keep a thermophilic pretreatment system at a lower pH, or maintain a larger reactor and mesophilic conditions at a higher pH to focus on methane production. Again, your methanogens being the key ingredient to making the value-added methane. It does pay to keep them preferentially happy over anyone else. So if you can dedicate a tank, a secondary tank to just their population growth, sometimes it can be proven worth it at the cost of expense, another tank.

But when both cultures coexist, the optimal pH is right between the two at 6.8 to 7.5. Moisture, as I said, the water. If too little water is added, you can get organic acid build up, pH dropping, and ultimately, AD failure. If too much water is added, as I said, the digester could become too diluted, which can reduce biogas or wash out. Methanogens require macronutrients, phosphorus and nitrogen as well as micronutrients. Most substrates during the due diligence portion of an AD process will test the substrate and determine what nutrients they're missing, what macronutrients and micronutrients, and they can have recipes tailored for their needs to be pumped in alongside the material into a digester to bring it up to the ideal level. Toxics – toxins, I should say. High concentrations of constituents like ammonia, calcium, chromium, copper, cyanide, magnesium, nickel, potassium, sodium sulfate, etc. These can be toxic for AD. Most of those, like the metal components, would be a function of the material coming into the digester, so what waste you are anaerobically digesting. Products like ammonium and hydrogen sulfide can be formed inside the digester as a function of their protein content. Proteins contain a backbone of nitrogen which contributes to ammonia production. They also are the only sulfur-containing components coming in with the R-groups on the proteins, which contribute to hydrogen sulfide formation. Again, both of these at levels can be toxic to the system. Next slide, please. Types of digesters. So, there's two main types. There's continuous digestion and then there's dry digestion, which is actually batch digestion, although there are versions of continuous wet digestion. A continuous digester is organic material is regular fed in, digested, and regularly removed periodically, usually continuously though, not periodically.

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A wet digester is a process with less than 12% total solids. Another type of continuous digester is a high-solids loading digester. Compared to a wet digester, it has higher total solids in the range of 12% to 20% total solids, and mechanically, they are usually designed different with more physical mixing. Couple nuances from wet digestion where everything is pumpable in liquid state, these require more – different styles of pumps because the material is less fluid. Like the alternative to a wet digestion or a continuous digester is a dry digester, where essentially, these look like large garage stalls, bays where the material is loaded with a machine into the front end. The door bays are shut, percolate from a previous digestion, is sprayed over this water with bacteria in it, is sprayed over the organics, and it sat and closed for 40 days. And like I said, the digestion occurs the same way it would in a continuous, but it's just batch. At the end of the 40 days, the bay is opened up. The material is reduced in volume, scraped out, removed, and reloaded for the next processing. Next slide, please. Here are examples of continuous wet digesters. These are by far the most common on the market. You can see here on the left there is a split screen where you can see the gas collection system above with a mixing system below, and two currently working systems in photo. Next slide, please. These are also continuous wet digesters but these are of the high-solids loading design. So you can see in the left picture, it's more of what's called a plug-flow. The material comes in one side, it goes down a channel, is reverted back down the same way. This allows the degradation to go past a normal steady state of a wet digester, which is continuously mixed. On the right here, you can see another operational plug-flow digester in the works and a little diagram below showing how they function, just left to right. Next slide, please. This is just a photo of the batch design I told you about. So, these doors would come up. They would shovel material in, spray the percolate onto it, shut them up, and they wouldn't open them until everything was digested, usually 30 to 40 days from that point. These can be very labor-intensive, as you can imagine, because rather than pumps moving the material around, you rely on people and machinery. Next slide, please. Applications for digesters. Standalone digesters, these are commercial digesters that are bringing in material for tipping fees from other facilities or producers that have the waste. They're looking at it from a waste management standpoint, whereas the developer or digester owner is looking at it from an energy producer standpoint. These can accept chicken waste, food waste, industrial processing waste, but essentially, they're developed independently from the waste material producer. Secondly, on farm digesters, these are manure management systems developed by the farm to reduce their onsite costs. And the third one would be municipally-run, city-run water treatment systems, water resource recovery facilities that have used anaerobic digestion to reduce the volume of their biosolids, and saving essentially taxpayer money. Next slide, please. Design and components of AD. Feedstock input, like I said, the balance of nitrogen and carbon determine digester efficiency, impacting biogas, and yield, and nutrient composition. There's actually a lot of different ratios and metrics to hit in terms of digester health, not just nitrogen and carbon, but there's volatile fatty – there's VFA over alkalinity and a lot of other metrics to determine whether your digester is healthy. But ultimately, knowing the feedstock input, consistency, and being able to expect that reliably is key to developing an AD system. The gas collection system is essential for capturing the produced biogas. The system must ensure a minimal loss while maintaining pressure stability. And retention time, optimal retention time balances digestion and gas production. Insufficient time leads to incomplete digestion and inefficiency, money on the table, essentially if you're going to produce it but not give it enough time to fully convert, you're not processing to your potential. Next slide, please. Challenges and limitations. Feedstock variability as we've discussed, and most of that is with contamination. Fluctuations in feedstock can impact the microorganisms. There, the best case

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scenario is to provide them as stable a living environment as possible. Economic barriers, traditionally, anaerobic digestion has had a high initial investment cost and along with market volatility, has kind of slowed widespread adoption of anaerobic digestion. Regulatory channels, strict regulations, and unclear policies can obstruct project development. This is largely impacting the operational and development feasibility. Although the recent investment tax credit in the US here has helped development interests. Next slide, please. Keys to digester success. The EPA considers the following factors key to any AD development success: And that is a plan for success. Don't develop a system that is unsure and possibly prone to failure. That may be obvious, but should probably be stated first, regardless. The second is recruit and secure an experienced team. This may seem obvious as well, but there's a lot of people out there who think building tanks and being in wastewater gives you the understanding for anaerobic digestion. AD itself is kind of a different monster, and there's a bit of an art that goes along with the science. So, experience will always be key in any AD system. You need people who have done it before and have seen systems run well but also seen them run poorly. Develop a sustainable business model, be conservative in your projections, and be honest about your projections as well. AD's development has a lot of different partners, both in the offtake, in the procurement, in the energy offtake, in the material offtake. So, honesty and transparency has been critical for successful projects. Securing feedstock, along with that kind of plan for success. You need to have secure feedstock and secure offtake agreements. Use the most appropriate technology. Analyze options for biogas and digestate use. That's probably one of the largest hurdles in developing these projects, is securing biogas and offtake contracts for values that are economically favorable for all parties. Developing the offtake agreements, evaluating the added benefits. Conduct community outreach, which is very important because I've seen the community involvement take more than one project, I should say, where the community was not educated, did not know the ins and outs of the AD system, and were against it, and ultimately failed the project. And then also, the last one that can't be overstressed enough is plan for operations and maintenance, because it happens more than you plan for it in every scenario. So with that, I think we'll end the AD portion of it. Any questions?

DANA BLUMBERG: Thanks, Erik. Yeah, we have a lot of questions here. So in the question box – I'll go ahead and read them. So the first question is: How much – what is the percentage of residual remains in an anaerobic digestion plant, the percentage of input of the waste?

ERIK ANDERSON: Good question, and that's a function of what the material is you're digesting. But in general, for instance, say food waste, academically, the number is 79%, 80% if you round up, of the material should be converted. So that's a 80% COD (chemical oxygen demand) BOD (biochemical oxygen demand) reduction, which usually correlates to similar in volume reduction as well. I have also seen manure is quite a bit less. Sometimes, you'll only get 30% or 40% reduction in manure because of the amount of total solids or inert material in it. So, the question – there is a range to the answer, but ultimately, you'd, in a high-performing digester that's been designed well, you'd be looking for up to 80% reduction.

DANA BLUMBERG: Excellent. And the next question, can we compare the nutritional value of digestate and compost prepared from the same kind of waste?

ERIK ANDERSON: Yes, yeah. That can be compared. Again, like everything, that's a subjective answer to the two types of materials being processed, but there are companies out here that do exactly that. They will take a nutrient analysis from digested organic material and they will offset fertilizers. They'll work with fertilizers and farmers to offset their fertilizer needs.

DANA BLUMBERG: Okay. Thank you. And I think the next question was answered further down in your presentation. They were asking for a schematic diagram of the anaerobic digestion plant. So, you did show them a schematic of the

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inside of the different digester types. So hopefully, that question was answered. And then let's see. The next question is: How much time is required to complete the anaerobic digestion process under normal conditions?

ERIK ANDERSON: Oh, good question. The general rule of thumb is 20 days, 21 days hydraulic retention time. And that's about – and you can think about it, whatever facility produces, if it's at the correct dilution already, you can multiply that daily production by 21. And that would be approximately the working volume of the digester for that facility. Now, that's not always the case and certain materials take more. There's a test called a biomethane potential test, a BMP, that allows you to, in a lab setting, determine what your ideal HRT (hydraulic retention time) is. It'll show you how much biogas you're getting out after certain days, and it'll tell you when you're essentially decayed on biogas. Your potential is gone after maybe 15 or 20 days, and that'll help narrow in your design time.

DANA BLUMBERG: Okay. And then hold on a second. What is the percentage of wastewater sludge that can be added to a waste – an anaerobic plant for waste? I'm assuming solid waste.

ERIK ANDERSON: Could you repeat? What is the percentage of it?

DANA BLUMBERG: Yeah, so like, how much wastewater sludge can you add if you have an anaerobic digester for, you know, municipal solid waste, like organic waste?

ERIK ANDERSON: Sure. And this is where it comes into the digester type. Certain digester designs can take higher solids loading. For wastewater treatment, the total solids are usually very low. You're looking at 3%, maybe 1% to 4% in total solids. And of that total solids, you may only get – or those total solids may only be 60% to 80% of volatile solids. So in those scenarios, you can't concentrate the organics anymore. It's already dilute. So, that would be the concentration you would send into a water – into an anaerobic digester at 1% to 4%. If the material was already higher in solids concentration, or I guess a better way to say this is the maximum you'd want to feed a wet digestion system is 10% solids, plus or minus. Some system design that you can feed 12% total solids, but most of them use as a rule of thumb, 10% total solids. So if you've got a material that's 10% or greater total solids, you can add water to it. If it's below that, then that is just the concentration of your feed going into your digester, if I understood that question correctly.

DANA BLUMBERG: Okay. Thank you. And then another question is microbes required to complete all stages of anaerobic digestion process will be generated automatically in waste, or to be added externally by the operators?

ERIK ANDERSON: Could you repeat the question? I didn't...

DANA BLUMBERG: Sure, yeah. So, microbes require to complete all stages of anaerobic digestion process will be generated automatically in the waste, or do they need to be added externally by operators?

ERIK ANDERSON: I understand. So initially, there is an inoculation. When you're studying a digester up for the first time after building it, you add in a ratio of inoculum, which is digestate coming from a different anaerobic digestion plant. Or if your system already has manure innately as a co-digestion or primary digestion product, the manure will bring in enough bacteria. The bacteria that's brought in with manure isn't necessarily the same population composition that will be in a full-fledged design, but bacteria have a tendency to change their genome actually over time to kind of adapt to the needs of the material. So if it came in eating one thing, over time, that population will adapt to the reactor. As I said, if manure is not part of it, yes, an inoculation phase does happen at the beginning, but once it's done, the bacteria propagate themselves. They will – and again, that comes with the HRT. So, you set this all to a timeline that you're guaranteed your population doubling or outrace your flow rate so you don't wash out material. You're making more bacteria faster than you're washing it through.

DANA BLUMBERG: Thank you. And then another question: Which option of anaerobic digestion, dry or wet, will have more biogas production from the same kind of feedstock?

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Which option is more productive one?

ERIK ANDERSON: I would say that that can be a subjective question, and relative to the material, I would say generally wet digestion is considered the kind of workhorse of anaerobic digestion. It's the most reliable and it's the most robust in that it is not as prone to – it can take higher hits, and variability in feedstock, and temperature swings and operational swings. Dry digestion is very labor intensive, and there is only a few successful projects in the US here. I think globally there are more that are doing it, but in the US, there's only a few commercial dry digester – digestions in operation. Traditionally, CSTR (continuous stirred tank reactors) would be the one that even if the day-to-day performance metrics were not as high as what a dry digestion or alternative would produce, the reliability over a year time frame or 10-year time frame, I think on average, you would produce more biogas from that, just from the uptime. Other systems with more control and more components tend to break down easier, and kind of best practice says keep it simple and you'll break down less.

DANA BLUMBERG: Thank you. Can only fresh farm manure be used for AD? And also, can old waste be used?

ERIK ANDERSON: Fresh manure is better than old manure. And the reason for that is the volatile components that are ideal for the conversion to methane, they're just that volatile. So if you don't collect the methane, the manure on the field right away, and especially if you – if it's in a position to be in sunlight, you'll get just natural evaporation of these value-added organic materials, and you'll get constant degradation. So as the material sits, it's still degrading, it's still forming these volatile components and then evaporating in the sun. And on top of that, you'll also get windblown debris, silica, dust. So the longer manure sits, the less volatile component it has and the more inert component it has. But there's also technologies that will play to that. So there are dried up – unlike the bay dry digestion that I showed where it's the large garage store, there are vertical dry digesters that tailor to dry cattle manure, so feedlot manure, manure that's scraped from the ground and then piled for eight months at a time. It still has lots of organic value to it, lots of carbon, but the biogas to feed ratio does go down as time goes on.

DANA BLUMBERG: Thank you. And I think this is our last question in the Q&A box: Can slaughterhouse waste be used with animal manure in an AD plant?

ERIK ANDERSON: Oh, absolutely. Yep. That is a nuance and kind of a – I've dealt with that with clients recently. And the one thing that kind of comes up is, slaughterhouses and other farms, especially in the Midwest, are prone to lagoon-style digesters, which are much more passive in their mechanical mixing. They're great for slaughterhouse wastewater, but when you add in the manure component, they're systems that the lagoon is not as ideal for manure digestion because solids can collect at the bottom without any method for being moved around. So, systems that do – slaughterhouses that have enough manure I've seen adopt a two-digestion approach. They'll do a CSTR and a lagoon system for the concentrate and the dilute materials.

DANA BLUMBERG: I don't know if anyone has any other questions that if they want to raise their hand or type another question in the Q&A, we have about two more minutes. All right, well, then I think we'll move on. And then if you think of something, we can – Erik will be here. We can ask him at the end. So, we will go ahead and move on to Hussain. Thank you.

HUSSAIN ALI: I'm Hussain Ali, and I will be going over the composting technique to break down or manage organic waste. Next slide, please. So, composting basically differs from anaerobic digestion by one factor, which is the presence of air. In composting, we break down the organic waste in the presence of air to produce nutrient-rich soil amendments.

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Some of the important factors in composting process are proper feedstock mix, moisture, oxygen, and temperature. Next slide, please. So, the goals for a composting facility, the first major goal is to produce a high-quality and consistent compost. The second goal is to comply with the regulations. We do not want odors or higher emissions coming out of our composting facility. Also, the facility, since the waste is – in some of the composting techniques, the waste is out in the open, we want to have a proper stormwater management at the facility, because if the water gets in contact with the waste, it produces leachate. And the last goal for a composting facility is to be cost-competitive. Since if it's not, if the compost is not competitive with the fertilizers available in the market, then it makes it harder for the composting facility owners to continue their work. Next slide, please. Coming towards the basics, like I mentioned earlier about the parameters, so the – one of the most important thing is to keep our feedstock balanced. We want a balance of carbon with nitrogen, just like anaerobic digesters. We need a C to N ratio of about 25 to 30 ratio one. The particle size is also one of the main factors that needs to be controlled. A smaller particle size will mean higher surface area and more space for aeration. Moisture content also needs to be controlled. If the waste is too dry, then it might take longer for the process to take place. But if the waste is too wet, then it might make the pile anaerobic. Next is oxygen flow. You have the composting process, it does need oxygen. If the oxygen flow is not there, then it can turn anaerobic and it can produce odorous gases like hydrogen sulfide. And the temperature also needs to be viable. If the temperature goes over, I think 70°C, then it might affect the bacterial population inside the piles. Next slide, please. So, coming towards different techniques of composting. There are many techniques available, but here, we'll be going over the four major techniques. The first one is windrow composting. It's the most simplest one. As you can see from the picture, in this kind of technique, we pile up our compost in long, narrow piles, or windrows, and then we use a machine to turn them periodically. And the reason we're turning them is to provide air or provide aeration and keep the whole process aerobic. This technique does take longer. It takes about three to six months for the compost to be ready. The good thing about this technique is the initial cost is low as compared to some of the other techniques. However, it does have a higher operational cost since we do need to periodically move the piles. Next slide, please. So, the second technique is aerated static pile technique. As you can see from the picture, the piles are not getting moved. They are static, as the name indicates, but we do need to provide air. So, that's why we provide oxygen and air from the bottom by using pipes. This kind of technique can also be called covered aerated static pile. The good thing about a covered pile is that it reduces the orders and the emissions. Since we can control the amount of air and temperature in this type of composting, we can increase our composting process, and usually, ASP (aerated static pile) takes about two to four months for the compost to be ready. It does have a higher initial cost because of the installation of the whole system, but the operation cost is lower as compared to some of the other techniques. Next slide, please. So in-vessel composting, you can see that in the picture, that there are big cylinders

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or vessels in which the compost is placed. And since it's sealed, we can easily control factors like moisture, temperature, and oxygen. This process is relatively faster than ASP. This can produce a compost within one to three weeks. It does have a higher cost, and one of the cons is that the capacity that you can operate, it is limited, since for windrow, you can have as long piles as you want, same for ASP, but for in-vessel composting, the compost, the capacity does hinder it from being used at a large scale. Next slide, please. So, the last technique that I'll be going over is the vermicomposting. In this technique, we use worms to break down the waste. One of the con is that we do need to keep the worms happy. So, if the temperature is a little bit higher, that can affect the growth of the worms. Also, the worms can attract some of the pests or some other – some flies and stuff like that. And also, it cannot be – it's harder for us to operate that at a large scale. So, that's why for large scale, usually we use windrow composting or ASP. Next slide, please. So, some of the challenges. The contamination of organic waste is, I think, one of the major challenge. We do not want our waste to be contaminated either by inert materials like plastics or metals or by chemical materials like pesticides or herbicides. So most commonly, the chemical contamination occurs from the yard waste. Sometimes, the yard waste gets sprayed by pesticide and it becomes a part of the compost. And because of the pesticide, they can hinder the growth of the microbes that are needed for the breakdown of organic waste. There could be seasonal limitations. Since we do need to have a proper carbon to nitrogen ratio, so we do need our brown waste and our green waste in a specific ratio to have a good feedstock. But during some seasons, we might have less amount of yard waste available so that might pose a challenge. Another thing is to manage odor, temperature, and moisture content. As I mentioned earlier, all of these are important factors and they can affect the time needed and also the quality of the compost as well. And the last one is to select the most suitable composting technology. There is no right answer on which one is the best composting technology. It all depends on the needs and requirements for the city. Next slide, please. Now, coming towards the best composting approaches I've mentioned earlier, the optimal ratio of carbon to nitrogen which is about 20 to 30 ratio one. So, we need optimal ratio of carbon-rich materials like dry leaves or wood chips to nitrogen-rich materials like food scraps or grass clippings. We do need to maintain adequate moisture level, oxygen flow, particle size, and temperature. Selection of composting technology and equipment does depend upon the requirements and needs of the community. And the feedstock should be free of contaminants, because if there are contaminants in there, they might just hinder the growth of the bacteria that are needed to produce compost. Next slide, please. Coming towards the emerging trends in organic waste management, we have gone through anaerobic digestion and composting, which are mostly used nowadays, but there are some technologies that do provide good pros going forward. Next slide, please. So, like some of the – with the new research coming in, we do see some of the technologies that show a lot of potential. Some of the technologies are black soldier fly larvae, use of termite gut bacteria, and hydrothermal carbonization. We're going to be briefly discussing about black soldier fly larvae here. These flies originated from South America, but they can now be found in different parts of Asia, Africa, and Europe. The good thing about the larvae is that they can feed on various types of organic waste. The larvae can also be converted into animal feed, and

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the good thing is that they do not produce any methane or leachate during this process. Next slide, please. So, here are some pictures of the fly itself and the larvae. And you can see them decomposing the organic waste. So, one of the good thing is that it's non-vector non-pest, and it does reduces the waste quite quickly. Each larvae can consume about two kilograms of organic waste throughout its life cycle, and it – a larvae, almost double the waste every couple of days – double its weight every couple of days. And in this whole process, what happens is the larvae decomposes the waste and digests it. It takes about 14 to 21 days for the larvae to be ready. And once the larvae is ready, we can harvest the larvae and use it as animal feed, because it is rich in protein and fats. And even the manure that is left behind by the larvae is rich in potassium and nitrogen, and they can be used to develop fertilizers. So all in all, it does not leave much behind. That is a good thing about this technology. There is no methane production. Like I mentioned, no leachate production, and it does provide a huge cost savings as compared to some of the other technologies. So, there is a good potential here that can be explored with BSFL (black soldier fly larvae) technology. Next slide, please. Now, Erik will take over for the value-added products from organic waste treatment projects.

ERIK ANDERSON: Okay. This is Erik Anderson again. Value-added products from organic waste treatment projects. So, this is going to extend beyond anaerobic digestion to compost and any end products of organic waste treatment, organic management itself. So, next slide. So, byproducts of organic waste management. Again, across the field of all types of organic waste, involved this discussion, as Ali just mentioned, compost obviously a huge beneficial value-added byproduct that we've been using for decades, centuries. Digestate coming from anaerobic digestion, all the uses that we discussed, most popular in the dairy and manure industry being that livestock bedding. Outside of that, I think the most popular avenue for digestate is land-applied soil remediation, both for the liquid and the solid. The biochar itself is a byproduct of pyrolysis or gasification, depending on the temperatures and profiles. We'll talk a little bit more about that here, but it's definitely an up and coming byproduct here in the US as companies marketing and forming just around the sale and sequestration of biochar. Next, animal feed is going to be another large byproduct for post-digestion and organic waste, particularly just food waste, reusing food waste directly rather than going to an energy producer. Biofuels have been quite popular for many years. We'll talk about those. Pulp and paper products, especially because a lot of the material coming out of anaerobic digestion or these processes is high in fiber content, fiber is one of the materials that is very slow to degrade aerobically or anaerobically, so it's usually a very prominent byproduct in a lot of the waste management strategies. Organic acids. Again, because of anaerobic digestion, one of those intermediate compounds are organic acids. And these can be removed midstream, concentrated, purified through distillation, and sold into specialty chemicals. And then lastly would be the processed organic fines. This is usually byproducts of processing. It's the very small residual organic material left over as a byproduct. Very fine material, very compactible, and there's uses for that, direct uses for that from a waste management standpoint. So, next slide, please. Digestate, again, this is the process coming from anaerobic digestion. Digestate is a nutrient-rich organic material remaining after the anaerobic digestion process. It comes in two forms: liquid and solid. Liquid digestate contains high levels of nitrogen, phosphorus, and potassium, making it ideal for use as a liquid fertilizer. It can be sprayed directly onto land depending on the area. Certain barriers for that – or certain areas have been

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prohibited, direct land application of digestate, unless it goes through a pathogen removal process or a sterilization process. These can be affixed to the back end of anaerobic digestion processing quite easily only if the economics justify it. Solid digestate can be dried, dewatered and dried, and used as a soil amendment. The drying depends on what the final use is. For a, say, farm bedding, you'd need to be quite dry, whereas soil amendment is more of a logistics and material handling issue of transportation. You can also use it as a bio cover material in landfills along with the POF (processed organic fines). Yeah, sorry. Next slide, please. Digestate, the production process, digestate is produced in biogas plants or organic waste, undergoes anerobic digestion. Applications, as a bio fertilizer in agriculture or as a bio cover in landfills, we just covered, to suppress odors and enhance soil stability, as one of its main reasons, as a cover in landfills. Environmental benefits, it promotes nutrient recycling, reduces the need for chemical fertilizers, and contributes to sustainable landfill management. Like I said, the digestate coming out, those nutrients do not change form relatively at all. So, what goes in is just as good as – or what comes out is almost as good as what comes in, and your future fertilizer needs just need to be offset a degree. And this company is out there that strictly deal in that manure and fertilizer management, so they'll test the digestate. They'll work with the fertilizer promoters to develop the ideal supplemental feeds to your digestate to create a complete digestion or a complete fertilizer package. Next slide, please. Biochar. Biochar is a stable, carbon-rich material. Production process, biochar is produced by the heating of organic materials such as wood in a controlled environment. The most popular method for producing biochar is pyrolysis. Pyrolysis is the thermal – what's the word? Thermal degradation of organic material, thermal evaporation in an oxygen-starved environment. So, you have the same material that would, in theory, be going into an anaerobic digester, but it goes into an environment of extreme heat without oxygen. And when this happens, the volatile organic material is vaporized, sent into the vapor space, and can be collected elsewhere, condensed elsewhere, or sent through fixed bed catalysts to be reformed into newer components. What's left over in this oxygen-starved environment is a partially-oxidized, carbon-rich material. You can see in the photo there, there's a little white, there's a little black there. There has been some oxidation there, but if controlled correctly, you should get a very charcoal-looking black material coming out. Biochar has a very high surface area because you've volatilized all of that short chain, low carboxylic, low carbo – low weight molecular – low molecular weight material inside the structure, leaving only the rigid carbon structure behind. So again, this has a high ability to retain nutrients and water, making it very beneficial for soil health. The high surface area is also used a lot in chemistry and chemical processing as a filter aid like charcoal. So, there's also companies specifically on the West Coast and California that are now creating biochar, just to bury it as a source of carbon sequestration. And they're somehow making money doing that, so interesting avenues for biochar. It's become more popular. Next slide, please. Biochar applications in agriculture. Used as a soil amendment to improve fertility, enhance water retention, and sequester carbon, thus mitigating climate change. Useful in landfills. Biochar can be mixed with soil to create a bio cover. Enhances the stability of the landfill surface and providing long-term carbon sequestration. The other real benefit that I see touted a lot in this is that it's a natural filter for organic materials. So, as a bio cover, the biochar itself will trap a lot of the volatiles stored below it, really helping in odor mitigation. Next slide, please. Animal feed. So, as mentioned, this is another pathway for ideal or pristine food waste. Organic waste such as food scraps and agricultural residues diverted from food processing and farming can be repurposed directly as animal feed. Again, this in theory is higher on the recycling chart than it is to be composted or anaerobically digested. If we can

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use it still, food for its intended purpose as an energy source for eating, why shouldn't the cows and animals benefit from it as well before going to a secondary reuse like composting or anaerobic digestion? Production process, waste is processed, sterilized, and sometimes even supplemented with additional nutrients to create safe and nutritious feed for livestock. Nutritional benefits, recycled food waste can provide essential nutrients for animals, reducing the need for commercial feed. A lot of times, that – although the nutrient content will survive through anaerobic digestion, the molecular nutrients, the vitamins can be broken down as a process and converted, and therefore it makes more sense to feed that energy content and that nutrient content to the cows upfront rather than after the fact. Environmental impacts, reduces the volume of organic waste sent to landfills, lowers methane emissions from waste decomposition, and supports sustainable agriculture. So, animal feed is an ideal pathway to consider, alternative to a high capital-cost mechanical process. Next slide, please. Biofuels. Biofuels are renewable fuels produced from organic materials, including biodiesel, ethanol, and bio-oil. Biodiesel produced through the transesterification of vegetables and animal fats, that was very popular here in the US over the last decade. There are still quite a few biodiesel plants producing biodiesel. Although in the market, I know in the US, renewable diesel, a pathway that makes a diesel analog that's structurally the same as petroleum diesel, has kind of beaten out the traditional biodiesel made from transesterification of oils. A lot of the oils and fats currently are going to renewable diesel pathways for production capacities that are 10 or 20 times what biodiesel produces a year in the US. I spent a lot of time in biodiesel in a former life. The second one, ethanol generated from fermenting sugars from crops like corn and sugar cane. A very large market here in the US. Ethanol production is very viable. The market goes up and down, But essentially, there are plants all over the US, and they're producing not just the ethanol but oil byproducts as well from the process itself, produces significant amounts of corn oil, which then can be used as biodiesel or renewable diesel substrates, feed substrates. Lastly, bio oil created from the pyrolysis of the organic waste. So just like that biochar, one of the other bioproducts, one of the other products of that process is a bio oil. It's very heavily oxygenated, and it needs to be heavily refined through distillation to get any pure products that would be used for as a fuel in the future. But it is a high energy oil, And there are a lot of uses being generated from it. Not as much commercially successful, but a lot of interest in it as it's available energy potential. Biofuels can be used in vehicles, machinery, or blended with traditional fuels to reduce carbon emissions. Biodiesel specifically blends into renewable diesel and petroleum diesel, per government mandates, and along with ethanol. So, environmental benefits, reduces the dependance on fossil fuels, that's the non-biogenic carbon sources that we discussed, lower greenhouse gas emissions, and promotes the sustainability – sustainable use of organic resources, which is that waste organic management. The byproduct, residual biomass from biofuels production can be used as a bio cover and landfill, aiding to moisture control and gas management. Excuse me. Next slide, please. Pulp and paper products. So, organic waste such as agricultural residues, wood chips, recycled papers can be processed into pulp and paper. These materials innately have a high fiber content, and as it was mentioned, these are materials that aren't readily broken down during anaerobic digestion. They can go through the process and act almost like inert materials coming out the back end, almost the same state that they went in. Waste materials are broken down into fibers, which are then processed into paper and cardboard. Environmental benefits, minimizes the environmental impact of traditional paper production, offsetting those traditional processes. Byproducts, residual fibers from the pulping process can make – can be repurposed as a bio cover material in landfills, aiding in moisture, and retention, and gas management. So yeah, these high

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retention fibers, the biochar, the paper pulp products, these are ideal substrates for bio cover for landfills because of that porosity, because of that moisture and odor retention. Excuse me. Next slide, please. Organic acids. Organic acids such as lactic acid, acetic acid, and citric acid are produced through the fermentation of organic wastes. Acetic acid is obviously one of the primary intermediates during anaerobic digestion, but all of these are produced at some point during the intermediate stages of breaking down larger chain organic acids. As carbons come off, you get shorter chains in these carboxylic acids, your free fatty acids that are converting to alcohols and acetic acid. At any point, that stream can be removed. The light organic acids can be vaporized off through distillation or stripping, and then recondense, purified later for sale. Production process, organic acids originate from the fermentation of sugars and organic materials. These organic acids are then purified and used in various industries. Used in food preservation, pharmaceuticals, cosmetics, and biodegradable plastics. Polylactic acid is a very popular plastic here in the US. It's large chains of lactic acid formed. You can tell it's those plastic bottles you get at the store that are very crinkly, have a high degree of PLA (polylactic acid) in them. So, a very popular renewable alternative to petroleum plastics. Environmental benefits, organic acids offer a renewable alternative to petroleum-derived acids and support a circular economy. This is a great thing. Next slide, please. Processed organic fines. So these are the particles that are – that come from a function of composting or mechanical treatment of organic waste, where larger chunks are broken down into finer, more manageable particles. The benefits, these are good compaction properties. POFs exhibit excellent compaction characteristics which help in creating stable and well-compacted layers when using landfills. This property is crucial for maintaining the integrity of landfill operations and minimizing settlement. Reducing odors, by covering waste with POF, the exposure of the organic waste to the atmosphere is minimized, which helps reduce unpleasant odors. Again, it's very fine processed fibers, lots of surface area to trap moisture, to trap odors. Next slide, please. Questions?

DANA BLUMBERG: Thank you. Erik. So, we have a few questions, and then we'd like to open up the – unmute a couple people and maybe discuss the black soldier fly and the marketing challenges that you all are experiencing. So, let me start with just a few questions. For waste from fruit and vegetable markets and green waste, which type of composting technique would you recommend? The vermicomposting or aerated stockpile?

HUSSAIN ALI: There is no right answer. It really depends on the needs, so what kind of scale are we talking about. If we're talking about large scale, then we should go with ASP. If we are talking about a smaller scale, then we can go with vermicomposting. Another thing that we need to look at is what kind of quality of the compost that we are looking at. If we want a really high-quality compost, then we should go with vermicomposting. And it also depends on what resources are available. If we have the technology or if we have the people who have more experience in one technology as compared to the other one, so it's really of a question on the requirements of the specific community.

DANA BLUMBERG: What are the potential regulatory or health concerns associated with vermicomposting in a densely populated area?

HUSSAIN ALI: I think the vermicomposting, the main factor is they can attract a lot of pathogens, so if they need to be properly managed. And another thing is stormwater management if – so we do not want to produce any leachate. So, these are the two things that need to be considered in a densely populated area. And for compliance, I think it varies from country to country and from state to state. So, it really needs to be checked at, like, what

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are the requirements in Pakistan.

DANA BLUMBERG: Thank you. And we were wondering if the CEO of BWMC would come off mute and give us an example of your experience using the black soldier fly and what your marketing concerns are. I think the question was...

CEO BWMC: Unmute me?

DANA BLUMBERG: Yeah. There you go. Thank you.

CEO BWMC: Thank you for a very knowledgeable session regarding the composting and vermicomposting. We already have used vermicomposting practices in Bahawalpur, and we are using black soldier fly for this purpose. But the problem which we are facing is that we are unable to market the black soldier flies in Pakistan, so it is no doubt a marketing challenge, but you may advise for some avenues where we can market our black soldier flies.

HUSSAIN ALI: What I have seen here in most of the European countries is that there are companies out there who market sustainable products, and since it is a sustainable product, if it's marketed as, you know, a product that's helping the environment and is not carbon-intensive in production. That might be one of the marketing techniques or marketing things that I would go for. It's also a growing technology, so it's going to – it's expected to take some time for it to reach a level where it can compete with the current animal feed.

DANA BLUMBERG: So how long have you been using the black soldier fly in...?

CEO BWMC: We are using black soldier fly in Bahawalpur since last one year. We got this idea from another city, and we just got half kilogram of black soldier fly from another city, and then we get it where in our – we have now in tons.

Once we reached about, we had two tons of the black soldier fly, and then we have to reduce the vegetable input or vegetable market input for that, those black soldier flies as we could not find out the marketing strategy for these flies. And we engaged in some other urgent tasks so we could not remain focus on that one. But now, after having learning through these sessions, we can go again on the same practice in a more systematic way.

DANA BLUMBERG: So is it the compost product from the black soldier fly process, or is it actually the larvae that...? I'm just asking the question.

CEO BWMC: Actually, we did this experiment to learn that how much waste is reduced by using the black soldier fly. Regarding the compost, the product of this process, for compost, we have certain legal complications in Pakistan for the marketing of the compost. For marketing of the compost, we have to get it registered with the agriculture department, which have very strict regulations regarding carbon nitrogen ratios, cation ratios, and some other ratios. So, we got tested the product of the black soldier fly in the form of the compost, but it could not meet the actual desired requirements of the agriculture department, which they mentioned strictly for the

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compost. So, at that stage, we did not pursue it. But now, as we are entering into an ADB (Asian Development Bank)-funded project, and we have about 65% of our waste in organic form, so we will do more focused interventions on this composting black soldier fly and all these organic waste treatment methods.

DANA BLUMBERG: So is there an opportunity to use that compost internally within the city as like the parks department, landscapers that work for the city? Is that compost still regulated, or is that something that you could use it for?

CEO BWMC: Yes. There is an opportunity. We have a horticulture authority in our city. It can be used for the landscaping of the city area or the localities near to the city, but we have to go for some systematic manner for this purpose. There are opportunities, but all those need some marketing strategies as well.

DANA BLUMBERG: Well, maybe like you said, the funding, the new funding that you're getting, that might be helpful, and able to improve the process, and help with marketing.

CEO BWMC: Yes, definitely.

DANA BLUMBERG: Patrick did you have any comments?

CEO BWMC: The funding will enable us to build our capacity in the form of the production, in the form of the packaging, and we can have the smaller packages for the households and large packages for the commercial units, and we definitely can go for better marketing strategies after getting the desired funding from the ADB.

DANA BLUMBERG: I wanted to ask if, Erik, if you have any experience with the black soldier fly, and if you had any thoughts on how they could improve the process.

ERIK ANDERSON: I don't. I'm sorry.

DANA BLUMBERG: You don't? Okay.

ERIK ANDERSON: No.

DANA BLUMBERG: Okay. So, well, thank you. I think that was an interesting discussion. I think we do have a couple more questions that have come in. So, how does vermicomposting compare with other composting methods in terms of efficiency and environmental impact?

HUSSAIN ALI: So, vermicomposting in terms of efficiency, I think it takes a bit longer than some of the techniques, like in-vessel is takes about one to three weeks, and ASP, it takes about two months, one to two months, but vermicomposting can take about two to four months. So, there's a time constraint associated with it. And what was the second part of the question?

DANA BLUMBERG: Let me see. And what are the efficiency and environmental impacts in terms of those?

HUSSAIN ALI: So in terms of environmental impacts, I think if it's done correctly, then there shouldn't be many environmental impacts. I mean, like, for technologies like covered ASP, it definitely reduces the odor and emissions. Same goes for in-vessel. So anything which is more controlled is going to produce less odor and less emission. Since vermicomposting is open, so it can produce some odor and some emissions as the waste is getting broken down.

DANA BLUMBERG: And then what infrastructure is required to establish a large-scale vermicomposting facility?

HUSSAIN ALI: So definitely, we need to provide temperature moisture. So, those are important parameters. Second thing would be to have the labor which is experienced and the equipment necessary to remove the worms from the compost once it's necessary, and equipment to provide proper aeration as well too. So I think that these are the most important parameters that need proper infrastructure for it to work.

[01:35:00]

DANA BLUMBERG: Thank you, and then please comment on the cation exchange capacity of compost and how to improve it.

HUSSAIN ALI: I'm sorry. What?

DANA BLUMBERG: Please comment on the cation exchange capacity of compost and how to improve it. Maybe Erik?

HUSSAIN ALI: Yeah, I'm not really sure about that. I think Erik can answer that.

ERIK ANDERSON: Of compost, I guess I'm not sure what the application would be for cation exchange. As a filter aid? Kind of what I would guess is kind of an odor control. I couldn't speak to any metrics or numbers on that, but it would be – I don't know if it would be cation affinity or what the – how it would work. So, I can't provide anything in depth on that.

DANA BLUMBERG: So, this question came from Syed. Did you want to come off mute and maybe explain the question, so maybe we can get an answer for you? Syed Osama Faheem Rizvi?

SYED OSAMA FAHEEM RIZVI: Hello? Can you hear me?

DANA BLUMBERG: Yes, we can.

SYED OSAMA FAHEEM RIZVI: Yes. So, I was asking about cation exchange capacity of the compost. Because if you want to use the compost as our fertilizer or as a soil additive, apart from the other factors, the cation exchange capacity, it's another important factor to be accounted for. So, I just wanted to learn that – how can we improve the cation exchange capacity of our compost, that our compost – how our compost can retain the anions or cations to better exchange of nutrients between the soil and the material?

DANA BLUMBERG: Erik, do you want to answer that?

ERIK ANDERSON: This is Erik. I couldn't answer that in any detail, I think. I know these are areas of study, and there's companies out there that specifically look into increasing the bioavailability of certain nutrients from composting phase into soil. So, it is being studied out there, but I can't offer any insight at the moment.

DANA BLUMBERG: Okay. And so, we have another question. What is the ideal summer and winter temperature for compost processing?

HUSSAIN ALI: I think the ideal temperature range is between 55°C to 70°C. And I think it needs to be maintained throughout the year since the microbes in there needs to have an optimal temperature for them to work properly.

DANA BLUMBERG: And then we have another question is: Can someone from the panel brief on bioreactor landfill site where organic waste can be converted to landfill gas in a more rapid manner? What could be the benefits of this type of landfill as compared to the traditional type of landfill if sustainability? So, I might just take that question. So in the US, we have been or had been experimenting with bioreactor landfills, and we found that the liquid load was really too much. And so, there was a lot of areas, I think, where if it's a wet climate, we would – our wells would get watered in. You end up with bigger chances of slope stability issues, and you really have to have a very robust leachate collection system and liner system. It does in theory increase the methane production, but it was – I don't think that it was a very successful – there was a trial period, and I think a lot of landfills just found it to be not successful and a lot more – causing a lot more problems. And then here, we have a question: If incoming food waste is not 100% pure,

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some shopping bags or other materials included, then how much does it affect the composting process?

HUSSAIN ALI: It can affect in a number of ways. For example, the first thing is the whole thing is not going to get decomposed. So at the end, it could be more labor-intensive to remove the plastic particles. The second thing could be aeration. For example, if you're using ASP, we have pipes that have small pores. And if small little plastic material gets stuck on those pores, then it can reduce the amount of air going into the piles. And another thing could be like rodents and some other insects can hide under some of these inert materials, and the quality of compost is also reduced, so it can have severe impacts on the compost.

DANA BLUMBERG: And does it also impact the marketability of your product?

HUSSAIN ALI: Yes. And also, I think it also impacts the compliance as well. So, there could be rules and regulation on how – the quality of the compost. So, if it has a lot of plastic particles in it, then it might not pass the regulatory requirement.

DANA BLUMBERG: What is the average maturation period of composting for food waste from households?

HUSSAIN ALI: I think it really depends on what kind of technique we're using. Like, we went over different techniques. Each technique has a different time period, so it depends on the technique that we're using.

DANA BLUMBERG: I think that we have answered all the questions in the Q&A, but if anyone would like to raise their hand and ask another question, or also we can have open discussion. So, just raise your hand if you wanted to ask more detail about your question or – we have some time here this morning. Not like yesterday, right? So... We have a little time here. Is there a raised hand out there? Let's see. Oh, yes. So, Syed, do you have another question?

SYED OSAMA FAHEEM RIZVI: No, no. I don't have. Thank you.

DANA BLUMBERG: Okay. All right. I think that was the only raised hand. So, we'll give you back a little bit of your evening. So, I'm going to turn it back over to Patrick. Thank you.

PATRICK COATARPETER: Great. Thanks so much. Thanks for facilitating that conversation, Dana. That was really great. Really happy to see some participation in there, some great questions as well. And thank you to all the speakers as well for the presentation. That concludes our training for today. Thank you all for joining. If you have any follow up questions, please feel free to email us at biogastoolkit@epa.gov. I'll also invite you to visit the Global Methane Initiative website for additional information on the topics covered today and much, much more. And to help us improve our training, please, I'll also remind you to fill out the feedback form that will pop up on the screen as the session ends today. And then as a reminder, tomorrow at 4:00 p.m. Pakistan Time, we have our third training in the series. This one will be on managing feedstocks to reduce methane, best practices for solid waste source separation. So, thank you again for your participation today. We really appreciate it. We look forward to seeing you all again tomorrow. Thanks very much. Take care.