Odor Control at RCRA Subtitle D Landfills

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Abstract

The ASTSWMO Solid Waste Disposal and Conversion Task Force has prepared this compendium providing an overview of the common landfill odors; meteorological conditions and operational impacts affecting the development and perception of landfill odors; and many options for landfill odor controls with corresponding case studies.

Prepared by the
Solid Waste Disposal and Conversion Task Force
of the Materials Management Subcommittee

Association of State and Territorial Solid Waste Management Officials (ASTSWMO)

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Disclaimer

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Odor Control at Subtitle D Landfills

1. Introduction

The Solid Waste Disposal and Conversion (SWDC) Task Force of the Materials Management Subcommittee within the Association of State and Territorial Solid Waste Management Officials (ASTSWMO) has produced this compendium as a resource for solid waste regulators and others for addressing the generation and management of landfill gas and odors. This compendium includes discussions of typical gases generated at landfills, the conditions that affect gas generation and migration, and potential remedies to landfill odor issues. In addition, it includes a summary of results from a nationwide survey on regulatory requirements regarding landfill odor, and case studies in landfill odor management.

1.1 Federal Odor Requirements

Operating criteria for municipal solid waste landfills (MSWLFs) is provided at Subpart C of Title 40 of the Code of Federal Regulations (CFR) Part 258 (40 CFR 258). The only mention of odors within these regulations is the requirement that operators of MSWLFs cover disposed solid waste with six inches of earthen material or approved alternate materials of an alternate thickness at the end of each operating day, or at more frequent intervals if necessary, to control disease vectors, fires, odors, blowing litter, and scavenging (40 CFR 258.21). In addition, MSWLF owners or operators are also required to monitor the concentration of methane gas and take immediate actions to protect human health and implement a remediation plan if stated methane concentrations are exceeded (40 CFR 258.23).

In addition to the federal regulations developed to implement Subtitle D of the Resource Conservation and Recovery Act (RCRA), the United States Environmental Protection Agency (USEPA) has also promulgated standards under the Clean Air Act (CAA) applicable to MSWLFs. These regulations[1] require the collection and control of landfill gas emissions, but do not directly require the control of odors. While the USEPA (1980) studied regulatory options for the control of odors, federal regulatory involvement was determined to be unwarranted, leaving States and local governments to regulate odor.

1.2 State Odor Requirements

State regulations often include landfill operating requirements and air quality requirements that regulate dust, odors, vectors, and other nuisances from impacting human health and the environment due to the operation of a landfill. In 2019, the ASTSWMO Solid Waste Disposal and Conversion Task Force sent a survey concerning State odor regulations applicable to landfills and requested examples of both successful and unsuccessful odor controls. Of the 40 survey responses, the majority of States responded that they have odor requirements in their regulations. Odor requirements were primarily found in solid waste regulations applicable to landfills. However, half of the responding States also indicated that air regulations included odor requirements applicable to landfills as well.

Within State solid waste and air regulations, the survey revealed that States have taken various approaches to regulating landfill odors. Most States reported that their solid waste regulations included

[1] 40 CFR 60 Subpart Cc—Emission Guidelines and Compliance Times for Municipal Solid Waste Landfills **OR** 40 CFR 60 Subpart Cf—Emission Guidelines and Compliance Times for Municipal Solid Waste Landfills; 40 CFR 60 Subpart XXX—Standards of Performance for Municipal Solid Waste Landfills That Commenced Construction, Reconstruction, or Modification After July 17, 2014 **OR** 40 CFR 60 Subpart WWW—Standards of Performance for Municipal Solid Waste Landfills

the RCRA Subtitle D language requiring that landfills apply and maintain daily cover to prevent landfill odors. Eighty percent (80%) of States also reported that their regulations have been expanded to include requirements that landfills (or generally any person or facility) shall not produce nuisance or objectionable odors that impact neighbors or the general public. Some examples of nuisance odor regulatory language provided by the States include:

- Odors and vectors shall be effectively controlled so they do not constitute nuisances or hazards;
- A person may not engage in solid waste handling in a manner which will likely create a nuisance;
- No person shall cause or permit the emission of any substance or combination of substances which creates or contributes to an odor, in the ambient air, that constitutes a nuisance;
- The owner and operator shall control nuisances, including but not limited to … odor. The facility shall be operated to control malodorous gases; and
- No person shall emit or cause to be emitted into the atmosphere any air contaminant or combination of air contaminants which creates an objectionable odor beyond the property line.

The use of terms like nuisance and objectionable can be difficult to interpret in the compliance setting. Of the 32 States that reported having nuisance odor regulatory language, twelve reported having a definition for "nuisance" and three provided definitions for an "objectionable odor." Most definitions of nuisance and objectionable odor were similar and included language that a nuisance / objectionable odor occurs when there is an interference with an individual's health, safety, welfare, comfort, convenience or enjoyment of life and property. One definition for objectionable odor took this further to state that "[o]dors are harmful or injurious to human health if they tend to lessen human food and water intake, interfere with sleep, upset appetite, produce irritation of the upper respiratory tract, cause symptoms of nausea, or if their chemical or physical nature is, or may be, detrimental or dangerous to human health."[2] Another method reported for determining an objectionable odor is "when 60% of a random sample of persons exposed to the odor in their place of residence or employment, other than employment at the odor source, claim it to be objectionable."[3]

Some States identified a requirement that landfills develop an Odor Plan identifying actions to be implemented by a landfill to control odor. Such a plan was either required as part of the original landfill permit application, the facility operation plan, or required to be developed in response to odor complaints.

Finally, five States reported that their State solid waste or air regulations include measurable odor standards applicable to landfills. Colorado, Kentucky, and Missouri had similar regulations prohibiting the emission of odorous air contaminants from any source that results in detectable odors using an olfactometer. In these States, it can be a violation if odors are detected after the odorous air has been diluted with seven or more volumes of odor free air. Minnesota, New Jersey, and New York provided information about air quality standards that included measurable hydrogen sulfide (H_2S) limits that could be cited for landfills with H_2S issues.

[2] North Carolina, 15A NCAC 02D.1801
[3] Wisconsin, NR 429.03(2)(b)

2. Elements of Landfill Odor

Most landfill odors are associated with landfill gas. Landfill gas is a product of decomposition of organic material in landfills and consists primarily of methane and carbon dioxide, which are colorless and odorless. Trace amounts of sulfides, nitrogen-containing compounds, and other non-methane organic compounds (NMOC) in landfill gas are the largest contributors to odors.

Other common sources of odors at a landfill include:

- *Incoming trash;*
- *Specific wastes with strong odors such as sludge from wastewater treatment plants, manures, animal carcasses, and some industrial wastes;*
- *Specific wastes, such as gypsum wallboard, which are known to contribute to hydrogen sulfide production during decomposition;*
- *Storage and transfer structures for landfill leachate, which is the liquid collected from the bottom of a constructed landfill unit;*
- *Installation and maintenance of landfill gas collection and control systems; and*
- *Other waste management activities occurring onsite such as composting.*

2.1 Methane & Carbon Dioxide

While methane and carbon dioxide, mentioned above, do not contribute to landfill odors, they can create health, safety, and environmental hazards when not managed properly.

2.2 Sulfur-containing Compounds

Landfills commonly accept sulfur-containing wastes, such as coal ash, municipal solid waste (MSW) incinerator ash, and construction and demolition debris, especially gypsum wallboard. Under the landfill's anaerobic conditions, bacteria in the landfill convert the sulfur in these wastes to H_2S, dimethyl sulfide ($(CH_3)_2S$), and methyl mercaptan (CH_4S). While the concentration of these compounds may be small, they are typically responsible for the greatest portion of landfill odor complaints due to their very low odor detection threshold. These sulfur-containing compounds are typically described as having an odor of rotten eggs or cooked cabbage.

2.3 Ammonia (and Other Nitrogen-containing Compounds)

Ammonia is produced in large quantities in landfills, but with a high odor threshold, it is not a major contribution to most landfill odor complaints. However, other nitrogen-containing compounds, including cadaverine, putrescine, and trimethylamine, which are produced by rotting meat, have much lower odor thresholds and have a much greater impact on landfill gas odors. While some are less noticeable individually, any or all of them in combination with other gases often produce an odor referred to as the "smell of death" (Techletter.com).

2.4 Non-Methane Organic Compounds

Many other compounds contribute to landfill gas odors based on the waste disposed, environmental conditions, and landfill operations. These can include aldehydes, carboxylic acids, and terpenes, which are produced during anaerobic decomposition. While individually, some of these may have a pleasant smell, they can increase the odor intensity when mixed with other landfill odor compounds.

2.5 Odors Associated with Landfill Fires

Landfill fires, both surface and subsurface, emit an odor similar to a charcoal grill or melting plastics. Responses to landfill fires are varied and specific to the situation, but recognizing them at an early stage is important. Surface fires are generally visible, either the smoke or fire itself, and can result from arson, disposal of hot objects, or other spark sources. Subsurface fires are less recognizable and caused primarily by combustion of buried organic material, often spontaneously. Unlike other gas production, this is an aerobic process caused by the heat of a buried object or degradation of organic material. Smoke might not be visible since compacted waste acts as a good particulate filter, but fugitive gases are able to

percolate towards the landfill surface. In general, landfill fires are a major concern because they "emit a toxic cocktail of 'Most Wanted' fugitive gases including formaldehyde, hydrogen cyanide, hydrogen sulfide, nitrogen oxides, and many others" (Foss-Smith, 2010).

3. Factors Affecting Odor Development

The presence, development, and atmospheric distribution of landfill gas and odors may be impacted by a variety of conditions at the landfill. Certainly, the meteorological conditions and their relation to the waste mass are a critical element to the development of gases and odors, and must be considered in the siting, design, and operations of the landfill. Additionally, changes in land use and development patterns in the area surrounding the landfill can influence the public perception of landfill odor over time. The following subsections present meteorological conditions and operational impacts that affect the development and public perception of landfill odors.

3.1 Meteorological Conditions

It is clear that weather conditions affect the production and dispersion of landfill odors and are a consideration when addressing how best to reduce landfill odors, particularly in the short term during unstable weather conditions.

3.1.1 Precipitation

The optimum MSWLF moisture content to maximize gas production (and thus odors) is 40% or higher. Since waste is typically assumed to have a moisture content as low as approximately 15% (Tchobanoglous, 1993), the addition of precipitation into the landfill waste mass is expected to increase waste degradation resulting in increased gas and odor production. Precipitation impacts landfill odor in two ways:

- Increased moisture content of incoming waste to the landfill, and
- Increased moisture content due to seepage into the landfill.

The increased moisture content of incoming waste may increase complaints of landfill odors near the landfill entrance, along internal haul roads, or odors from the working face. Disposal of wetter waste in addition to precipitation seeping into the landfill at the working face or in areas without final cover or poor drainage can increase the overall moisture content of the landfill, thereby increasing gas and odor production.

3.1.2 Humidity

An increase in landfill odor is often reported as rising with high humidity due to the heavier humid air entrapping the odors and allowing them to linger and stagnate. Work by Ying et al. (2012) indicated no direct correlation to humidity, but did note that temperature inversions result in the combination of stagnant and humid air and resultant odors. Therefore, humidity and odor may not be directly related but mutually common under certain atmospheric conditions.

3.1.3 Temperature

As ambient temperatures rise, it stimulates molecule movement in landfill gases, which increases odor diffusion. In summer, although temperatures increase, other conditions, such as high barometric pressure, dry air, or winds, may provide a counterbalance to mitigate dispersion of landfill odors. In winter months, while less odor may be produced, conditions such as low wind and temperature inversions may cause greater dispersion of the odors. While seasonal temperatures can affect odor dispersion, odor complaints are received year-round.

3.1.4 Temperature Inversions

Temperature inversions, occurring when a layer of warm air overlays a layer of cooler air, limits the convection of air near the ground surface. This impacts the "diffusion of dust, smoke, and other air pollutants" and "a ground inversion develops when air is cooled by contact with a colder surface until it becomes cooler than the overlying atmosphere" (Encyclopædia Britannica). Topography greatly affects the magnitude of ground inversions. If the land is rolling or hilly, the cold air formed on the higher land surfaces tends to drain into the valleys, producing a larger and thicker inversion above low ground and little or none above higher elevations. Temperature inversions may enable landfill odors to travel to lower terrain areas many miles without dispersing.

3.1.5 Barometric Pressure

On days when the barometric pressure is lower than the pressure of the gases within the landfill, more gas will escape into the atmosphere. Similarly, landfill operators have attributed the use of more aggressive vacuum on gas collection systems or improvements to the gas collections system, which reduce gas pressure within the landfill, with reductions in odor complaints.

3.1.6 Wind

Wind contributes to spreading landfill gas, increasing the potential area of impact, but can also reduce the concentration. Ying et al. (2012) noted that landfill odor complaints were confined to a downwind area comprising of only 225 compass degrees. However, when little or no wind is present, odors will tend to be more noticeable.

3.2 Operational Impacts

Various operating systems at the landfill can have a significant positive or negative impact on the development of landfill gas and dispersion of landfill odors.

3.2.1 Landfill Gas System

Landfill gas collection systems are designed to collect and manage the gas produced by a landfill over time. The designs are based on modeling of the gas generation over the operating life and the post closure care period of the landfill. If the gas generation is underestimated, the limitations of the system can cause excess gas pressure within the landfill, which will escape and increase odors. Conversely, over-expanding the gas system or increased vacuum can result in reduced gas pressures and introduction of oxygen to the landfill and cause potential development of landfill fires. It is essential to calibrate the gas system appropriately for the actual gas generation of the landfill.

3.2.2 Landfill Cover

Landfill cover, which includes daily cover, intermediate cover, and final cover systems, are important in managing landfill gas. A daily or intermediate cover of a finer grain material may help reduce migration of landfill gases through the waste. Conversely, use of a gravel or coarser grain material may provide fewer resistant pathways for the gas to migrate through the cover material. Cover material should be a consideration in the overall gas management system. Final cover for most landfills includes a generally impermeable layer, and must include penetrations for gas collection during the post-closure period of the landfill.

3.2.3 Landfill Leachate Management

Landfill leachate can produce significant odor in itself. Leachate is commonly collected in tanks or ponds prior to being processed, disposed, or recirculated into the landfill. Leachate management storage and processing should be considered in landfill design and development. Open storage or processing areas should be located in areas that are not likely to disperse odors easily. If leachate is recirculated, the increase in production of landfill gas must be considered in overall landfill gas management.

3.2.4 Specific Waste Streams

3.2.4.1 Animal Carcasses & Manures

Odors from animal carcasses are caused by the release of a combination of sulfur dioxide, methane, benzene derivatives, and long chain hydrocarbons produced as various body parts decompose. The odors from animal manures vary depending on the animal and its diet. The primary odor sources from animal manures are ammonia and H_2S, but bacteria in the manure also contributes to the release of various volatile organic compounds (VOCs).

3.2.4.2 Sewage Sludge/Biosolids

Similar to animal manures, sewage sludge, also referred to as biosolids, generated from wastewater treatment plant (WWTP) operations contains odorous sulfur and ammonia compounds. The concentrations and types of odors can vary depending on the WWTP operations. Treatment for odors can occur at the WWTP, prior to leaving the facility, and may include the addition of iron or lime to the sludge. It is estimated that about 30% of sewage sludge and biosolids produced in the U.S. are disposed in landfills (Rauch-Williams, 2018).

3.2.4.3 Construction and Demolition (C&D) Waste

Construction and Demolition (C&D) waste is a non-hazardous waste stream generally resulting from the construction, remodeling, repair, and demolition of utilities, structures, and roads. Gypsum wallboard is a common component of C&D waste. USEPA has estimated the composition of C&D waste to contain approximately 10% discarded gypsum wallboard by weight (USEPA, 2014). Gypsum wallboard consists primarily of hydrated calcium sulfate and has been identified as a major contributor to H_2S production in landfills.

Recycling of C&D waste is becoming increasingly popular, and usually occurs at a facility where the waste stream is sorted and processed. Post processing, the remaining material is a fine-grained waste often referred to as C&D residuals, C&D fines, or recovered screen material (RSM). This waste by-product is typically sent to a landfill for disposal or is sometimes reused at the landfill as an alternate daily cover or a surfacing agent atop landfill roads. Due to the increased surface area of these particles, and presence of organic material, gypsum, and moisture in the landfill, more rapid degradation occurs and contributes to landfill odors.

In addition to the odor controls discussed in Section 4, additional information specific to the development and control of H_2S from the disposal of C&D waste in MSWLFs can be found in Appendix B.

4. Odor Control Options

Odors are always going to be associated with landfill operation; however, there are operational and design strategies and improvements that landfill operators can employ to minimize odors and prevent nuisance conditions. Good odor control begins with good design and operations, but also requires practical preventative measures, active odor alleviation programs, and maintenance of existing systems. These strategies and improvements are discussed herein.

4.1 Landfill Operations

State landfill regulations often include landfill operating requirements, incorporated from 40 CFR 258, Criteria for Municipal Solid Waste Landfills. These requirements serve the purpose to limit dust, odors, vectors, and other nuisances from impacting human health and the environment due to the operation of a landfill.

4.1.1 Work with the Generator

For wastes that are known to be problematic, it is recommended that operators work with the waste generators to both reduce the odor potential prior to transport to the landfill and to coordinate delivery of the waste. Management options include assessing the production of the waste material to determine if any changes in delivery schedule or frequency, or the addition of odor control products prior to transportation, may mitigate or reduce odors during disposal. Ensuring that wastes are received at the landfill on a schedule that allows for them to be rapidly incorporated with MSW or covered may also diminish the potential for nuisance odors.

4.1.2 Application and Maintenance of Cover Soils

One method to control odors at the landfill working face includes the application of daily cover. State regulations often require the application of daily cover for MSWLFs consisting of six inches of earthen material. Alternate daily covers may also be allowed with State approval. Alternate daily covers may include the use of spray-applied products, tarps/fabrics, contaminated soils, or beneficially used waste materials. Approval for alternate daily covers typically includes a demonstration of their ability to control odors equivalent to soil daily cover. Some alternate daily cover materials may control odors better than others, and States may need to reevaluate a facility's approval to use alternate daily covers if odors are not adequately controlled.

In addition to daily cover, State landfill regulations may require the installation of additional compacted soil (often referred to as intermediate or interim cover) when an area of the landfill is not planning to receive additional waste within a specific timeframe. This additional soil cover serves the purpose to further reduce odor emission as well as provide for additional protection against potential exposed waste due to erosion. In an effort to control odors, it is recommended that landfill operators maintain the continuity and thickness of daily and intermediate covers, correcting any erosion or cracks in the soil covers which may allow odors to escape. It is also recommended that landfill operators maintain run-on and run-off controls to promote positive drainage, prevent erosion, and prevent ponding on the landfill.

In some cases, the installation of a temporary geomembrane (or synthetic cap) can be used in place of additional interim soils. Use of a temporary synthetic cap may come at a higher cost but does offer greater erosion protection, as well as improved gas collection and odor control. The temporary synthetic cap can incorporate the design and installation of a landfill gas collection layer underneath the geomembrane, consisting of porous media and piping with connection to a blower

station to collect and transport landfill gas to prevent ballooning of the geomembrane. Collected landfill gas could be routed to an existing landfill gas control system such as a flare or gas to energy plant. The synthetic cap design needs to include anchoring of the geomembrane or a ballasting system (e.g., use of sandbags) to prevent wind uplift and sliding. These synthetic caps can be installed in targeted locations of a landfill with problematic or concentrated odor issues.

Ultimately, the installation of final cover systems can also reduce odors, especially when the final cover includes an impermeable layer such as a geomembrane. If interim capping is proving insufficient to control odors, requiring the installation of final cover on a faster timeline than may have been originally planned may be necessary.

4.1.3 Landfill Gas Collection and Control Systems

As noted above, landfill gas, the byproduct of landfill decomposition and consisting mostly of methane and carbon dioxide (odorless gases), often contains trace quantities of sulfides, ammonia, and other volatile organic compounds which are responsible for odors associated with landfill gas.

The subsurface migration of landfill gas away from the landfill may create public health and safety hazards due to the potential for asphyxiation and explosion from the buildup of landfill gas in nearby inhabited structures. State solid waste regulations often include the requirement that landfills monitor and prevent the subsurface migration of landfill gas. In addition, MSWLFs that exceed specified design capacity thresholds are required under State or federal air regulations to estimate or measure the emission rate of landfill gases and install and maintain gas collection and control systems (GCCS) in accordance with MSWLF New Source Performance Standards (NSPS)[4] or Emission Guidelines[5] (EG), as applicable. While odor is not mentioned in these air regulations, the collection and control of landfill gas through flaring, gas to energy, or other methods can reduce the off-site impact of odors from the landfill.

4.1.4 Leachate Management

In addition to the high levels of organic and inorganic compounds that can be found in leachate, odor compounds can also concentrate in these liquids, which in turn can cause nuisance odor problems at the landfill and at onsite wastewater treatment facilities, if applicable. If odor issues occur at these locations, onsite treatment systems or pretreatment of the leachate prior to off-site transfer (e.g., coagulation/flocculation, oxidation, activated carbon, chemical treatment, or other filtration) are options. However, it is also noted that some onsite treatment systems, such as evaporation, may cause additional or prolonged nuisance odor conditions.

Leachate recirculation may also affect odor potential at a landfill. Leachate recirculation increases landfill gas generation rates in comparison to conventional dry cell landfilling, and the physical aeration of the leachate during application can cause nuisance odor conditions to develop. Adjustments to operating conditions may be sufficient to manage the increased odor potential.

[4] 40 CFR 60 Subpart XXX—Standards of Performance for Municipal Solid Waste Landfills That Commenced Construction, Reconstruction, or Modification After July 17, 2014 **OR** 40 CFR 60 Subpart WWW—Standards of Performance for Municipal Solid Waste Landfills

[5] 40 CFR 60 Subpart Cc—Emission Guidelines and Compliance Times for Municipal Solid Waste Landfills **OR** 40 CFR 60 Subpart Cf—Emission Guidelines and Compliance Times for Municipal Solid Waste Landfills

4.1.5 Odor Complaint Response

When responding to an odor complaint, it is important that State staff document the odor complaint and follow-up with the facility named in the complaint. Training programs are available to both regulators and operators to help improve understanding of what odors are and what could potentially be a nuisance. Participation in a training program can help ensure that landfill and regulatory staff are responding similarly and consistently to odor complaints, and mutually are achieving an effective response program. The following suggestions are provided for State regulators as possible options for either State staff or landfill operators to consider in responding to odor complaints. Several of the State case studies outlined taking these actions when responding to odor complaints with success.

First and foremost, it is recommended that landfill operators inspect both the area of the complaint and the landfill, including onsite waste areas such as citizen waste drop-off areas; stockpiles of wastes for beneficial use; landfill gas, leachate, and stormwater collection, conveyance, and storage systems; and any other areas that could possibly generate odors. Upon the detection of odors onsite or identification of issues such as inadequate landfill cover, erosion, leachate seeps, disconnects in gas, leachate, or stormwater conveyance features, etc., it is recommended that landfill operators take immediate actions to reduce odors or correct issues, such as applying cover soils, fixing connections in landfill gas collection lines, or apply other temporary relief measures, such as additional application of odor control products, until other appropriate actions can be taken.

States may also wish to send staff to conduct similar inspections of the landfill and surrounding area to independently assess the on and off-site presence of landfill odors.

For landfills that have continuing odor complaints, States and landfill operators may want to consider conducting community outreach. Outreach may include establishing a point of contact to receive landfill odor complaints and provide updates to complainants. Additionally, it may be beneficial to provide regular status updates to the community on the progress of odor control activities through recurring webpage updates, email communication, social media postings or in-person meetings. If outreach includes regular updates to the community, it may also be beneficial for landfill operators to communicate future construction activities at the facility that may result in temporary odor issues, such as the drilling, installing, or servicing of landfill gas collection and control components or liner construction tie-ins.

In some cases, the contracting of a third-party odor response consultant may be recommended to provide independent evaluation and reporting to the landfill, the State and the public. This may be most beneficial when there are significant discrepancies between the landfill's evaluation and response to odors and the public's perception and reporting of odor complaints, situations that prevent a rapid response by State personnel, or following a period of prolonged odor complaints when successful documentation of nuisance odors may impact further State legal action.

It is recommended that States and the landfill operators have mutual access to odor response logs that are completed by either party responding to persistent odor complaints. These response logs should include information on weather, landfill operations, odor (detection, type, and strength) and contact information of the complainant and who responded. Actions taken to respond to documented odor issues should be logged in order to be able to review whether certain areas have been consistently problematic, or if each response action is attaining the desired reduction in odors. If odors persist even after making operational adjustments, the facility may need to install or expand

landfill gas collection and control infrastructure. Additionally, there are odor control products on the market, as discussed in Section 4.2, that could be evaluated and used to help in mitigating odor nuisances.

4.1.6 Odor Management Plans

Some States[6] require the development of a plan specific to the identification, response, and control or remediation of landfill odors. These plans vary in intent, but typically serve the purpose of documenting the landfill operator's response to detected landfill odors as described herein. It is suggested that these plans be reviewed and updated to account for changing landfill operations and odor control methods and technologies.

4.2 Odor Control Products and Technologies

In addition to the landfill odor control methods identified above regarding landfill operations, there are also various products and technologies available that continue to evolve and can be used to address landfill odors. The following information is provided as overview, but is not an exhaustive listing of products and technologies available. See the case studies provided in Section 5 for more information on practical application of these technologies.

4.2.1 Fogging/Misting Systems

Many landfills can benefit from implementing the use of high-pressure fogging systems when they require supplementary odor control. These systems can utilize either neutralizers/counteractants, which are often essential oil based, or masking agents. Masking agents alone often are not as effective, as high application rates of a fragrant masking agent can separate from the landfill odor and the fragrance itself can become a nuisance. In order for these systems to be successful, there must be a clean water source available for flushing and to minimize clogging and the landfill operators must take responsibility for the systems, not only maintaining, but also operating the system at appropriate times, if the system is not operated continuously.

4.2.2 Vapor Systems

Vapor systems provide a highly mobile option for the application of an oil-based odor neutralizer that absorbs the malodorous molecules to minimize or eliminate odor transport off-site. The primary benefit of these systems is that they can be mobilized to remote areas, where a water source is not available, and they have multiple options for distribution at these locations (flex pipe, hard pipe, fence line etc.), though compressed air is necessary for operation. For these systems, either the odor neutralizer can be pumped into the airflow stream or the air can pass over a saturated wick.

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[6] Florida – 62-701.530 FAC, Section (3)(b) requires submittal and department approval of an odor remediation plan describing the nature and extent of the problem and the proposed long term remedy
Pennsylvania – 25 PA Code §273.136 requires municipal solid waste landfill applications to include a nuisance minimization and control plan addressing vectors, odors, noise, dust and other nuisances not otherwise provided for in the permit application
Texas – 30 TAC §330.149 requires that the site operating plan must have an odor management plan that addresses the sources of odors and includes general instructions to control odors or sources of odors.
Virginia – 9 VAC 20-81-200.D. Odor Management – requires development and implementation of an odor management plan to address odors that may impact citizens beyond the facility boundaries

4.2.3 Wash Stations or Pelletized Neutralizer

In some cases, off-site odors may be directly related to the vehicles transporting waste to the landfill facility rather than the operations at the landfill. This can be particularly true for known odorous loads, such as sewage sludge. The application of an odor neutralizer, either as a spray or as pellets, within the empty transfer trailer prior to its departure from a landfill facility may reduce these off-site impacts.

5. Case Studies

As part of the Landfill Odor Survey conducted by the ASTSWMO Solid Waste Disposal and Conversion Task Force in the Spring/Summer of 2019, States were asked to share examples of landfill odor controls that worked well, as well as examples of odor controls that were unsuccessful. While some States had little experience with odor issues at landfills due to the remote locations of landfills, or noted that adequate application of daily cover was effective at preventing landfill odors, others reported that resolving odor complaints can require multiple iterations, and there is unlikely a one-size-fits-all solution. The following sections highlight the examples provided by State survey respondents corresponding with odor issues and control options discussed in this document.

5.1 Management of Animal Carcasses & Manures

No specific examples were provided about management of animal carcasses. However, typical management strategies include the notification to the landfill that one or more animal carcasses are anticipated for delivery. This allows the landfill personnel to prepare an area for the immediate disposal and covering of the animal carcasses. Texas Regulation[7], as discussed in Section 4.1.6, requires that landfill site operating plans include an odor management plan that includes general instructions to control sources of odors, and specifically names dead animals, along with other potentially odorous wastes, as an odorous waste requiring special attention.

No specific examples were provided about landfill management of animal manures either; however, guidance to farmers and animal feeding operations with respect to management of odors can be applicable to landfill operations as well. State Agriculture Departments and University cooperative extensions may be a source of guidance when dealing with odors from animals (carcasses and manures). One such example is guidance from the University of Massachusetts Extension (see References) providing odor control strategies specific to manures.

5.2 Management of Sewage Sludge

Survey responses from Vermont, New Hampshire, Kentucky, Kansas, and Maryland all included case studies with comments about the management of odorous sewage sludges. Vermont, Kansas, and New Hampshire all mentioned the pretreatment of sludge by the generator. Vermont also mentioned the landfill required scheduling appointment for sludge delivery so that landfill workers are prepared to manage and cover the sludge immediately upon arrival. Kentucky and Kansas also mentioned that facilities enforced limited hours when sludge could be accepted (acceptance when weather conditions allowed for greater odor dispersion). Maryland reported some success with using potassium permanganate or lime on persistent sludge odors.

[7] Texas – 30 TAC §330.149 requires that the site operating plan must have an odor management plan that addresses the sources of odors and includes general instructions to control odors or sources of odors.

5.3 Management of C&D Waste

Tennessee mentioned having numerous Class III MSWLFs that accept C&D waste consisting of a large percentage of building demolition wastes that include wallboard. This has resulted in the generation of H_2S at a rate where odors have become troublesome to surrounding neighbors. In these instances, strict adherence to Best Management Practices (BMPs) has been critical. These BMPs include more frequent and thicker application of soil cover to control fugitive emissions and aid in mitigating odors. The addition of H_2S attenuating materials (wood chips, lime, etc.) in the soil cover also provides some extra odor mitigation. Tennessee reported that landfills using sulfur capture / neutralization chemicals vaporized or misted at the perimeter of the landfill also appear to provide some odor reduction. Operating the facility to prevent storm water from entering the waste mass (proper daily and interim cover, storm water berms, minimizing working face, etc.) is perhaps the most important BMP as moisture in the C&D waste typically results in higher H_2S generation rates. Finally, removal and recycling of the wallboard component of the C&D waste before it enters the landfill results in the greatest reduction of H_2S generation; therefore, reducing odors. Tennessee noted that wallboard removal and recycling is expensive and logistically complicated, and currently, they only have one facility undertaking this practice.

Rhode Island mentioned a C&D Landfill that was receiving daily odor complaints from the surrounding community. In the beginning, the State required the landfill owner/operator to apply good daily cover and use Posi-shell®, which yielded some success; but the complaints did not stop. Rhode Island then required the installation of a landfill gas treatment facility. The facility installed two (2) small flares to covert H_2S to SO_2 through combustion; however, residents continued to complain due to the SO_2 emissions from the flares. Finally, the State requested the installation of a gas pretreatment facility. The landfill owner/operator installed a sulfate/sulfur treatment facility and finally the landfill came into compliance.

5.4 Odor Misting and Neutralizing Systems

Mixed reviews were provided on odor misting and neutralizing systems. Connecticut mentioned that initially most sites attempt to mitigate odor issues with masking agents and additional cover soils, but odors tend to persist and resulted in the need for landfill gas collection and control systems. Michigan indicated that a perimeter odor neutralizer aerosol system is not effective when used as a stand-alone measure, but is useful as a component of an overall odor control strategy.

Maine highlighted a special waste landfill that accepts limited MSW. The facility's odor management plan includes provisions to control waste and leachate odors as well as monitoring surface emissions of H_2S on a real-time basis using stationary monitors. Waste odors are controlled using daily cover, minimizing active open areas, and maintaining an active gas collection and control system with sulfur treatment. Odor mitigation efforts to control off-site migration include the use of a dozer-mounted odor neutralizing spray system, and a perimeter odor misting system. Leachate odors may be controlled using odor reducing chemicals. Odors during truck transport are controlled with a spray neutralizer as needed. Daily odor surveys are performed to evaluate the success of the odor mitigation program.

5.5 Gas Collection System Installation and Expansion

Idaho highlighted a MSWLF, whose local government owner (county) was proactive in addressing odor problems. The county created a webpage to submit and log odor complaints and provide updates to the community. The county installed a gas collection and control system comprising a gas-to-energy system and flare, covering approximately 80% of the total landfill area. This installation and operation have pretty much resolved the odor complaints.

Iowa also referenced success in reducing odors at two MSWLFs by either adjusting or expanding gas collection and control features.

Wisconsin indicated that many landfills in their State have experienced odors and the primary means for controlling them have included installation and operation of a gas extraction system. Wisconsin reported that often these systems are operated earlier than required by regulation, and additional measures such as applying additional cover (intermediate), installation of temporary gas collection wells, and supplemental gas collection from toe of slope collection pipes or leachate collection lines have been employed to improve operation of the gas extraction system and control odor.

Louisiana cautioned about a MSWLF that was the subject of numerous odor complaints in 2018. The State did extensive odor surveys inside the landfill's property and outside the perimeter to confirm the origin of the odors and confirmed detectible levels of H_2S gas at several points on the landfill's property. Initially the facility tried to reduce emissions by pulling stronger vacuum on the existing active gas collection wells. This was ineffective and introduced oxygen above 5% in the landfill (a subsurface fire / oxidation hazard). Eventually, the solution was to expand the gas well field to better collect landfill gas as well as apply additional daily/interim cover and to reduce leachate levels, which have reduced emissions and odors.

5.6 Surface Emissions Monitoring to Detect Odors

MSWLFs subject to NSPS and EG regulations may already be performing surface emission monitoring for methane and reporting information to State air division staff. While methane is odorless, as discussed in Section 2, trace amounts of odorous compounds in landfill gas can result in odor nuisances.

Borrowing from the air NSPS and EG regulations, Virginia has added quarterly surface emission methane and H_2S monitoring requirements to solid waste permits for two MSWLFs with recurring odor issues. In both instances, the monitoring was required to determine the efficacy of both traditional soil daily and intermediate cover as well as approved alternate covers at controlling odors and included the requirement to monitor the working face after cover has been applied and before new waste application. Monitoring for methane and H_2S at the landfill surface allows the facility to make repairs to eroded cover soils and landfill gas collection components in areas where monitoring determines concentrations are above permitted thresholds (H_2S above 0.10 ppm and methane above 500 ppm). This data also allows the Virginia Department of Environmental Quality (DEQ) to better evaluate alternate daily cover usage and a mechanism to revoke approvals of alternate cover materials as appropriate.

Michigan shared that they employed a continuous H_2S meter to document the extent of the odor problem at two landfills. This data helped them convince the landfill operators that action was necessary to control odors and gas, resulting in these facilities installing or expanding their gas collection and control systems.

5.7 Synthetic Cap

Two States (Missouri and Ohio) shared stories involving landfills that installed ethylene vinyl alcohol (EVOH) cover systems or similar odor control blankets to mitigate and control odor releases from landfills. The EVOH cover system typically consists of multiple linear low-density polyethylene (LLDPE) or high-density polyethylene (HDPE) layers encapsulating an inner EVOH core that serves as the primary odor and landfill gas barrier. In both States, landfills were experiencing subsurface smoldering events and/or elevated temperatures, resulting in increased gas production and increased odors. The installation of an EVOH cover, in conjunction with a GCCS, was one part of the overall remedy to controlling and mitigating odors at these landfills.

Missouri reported on a landfill that experienced increased odor production resulting from an elevated landfill temperature. They employed the use of an EVOH cover consisting of a 40-mil HDPE geomembrane with an EVOH core, coupled with an expanded gas collection and control network. These controls nearly eliminated all off-site odors. Missouri also noted that an incredible amount of effort is expended every day to operate, maintain, and monitor the cover and GCCS.

New York also mentioned the successful use of sacrificial geomembrane over portions of two landfills with additional gas collection features in order to control odors.

5.8 Multi-pronged approach

The following examples highlight facilities that took multiple iterative steps to address landfill odors using more than one odor control method.

Virginia: Beginning in January 2015, citizens of a nearby subdivision began complaining about odors from a regional MSWLF in Virginia. The regional landfill is subject to federal NSPS for MSWLFs based on its design capacity; however, the facility's calculated emission rate had not yet triggered the NSPS requirement to install a gas collection and control system. In response to the complaints, Virginia DEQ staff completed a focused compliance inspection to assess the landfill's working face, compaction and cover activities, and nuisance odor controls. Following the inspection, the facility updated its Odor Management Plan and initiated a series of steps to mitigate the odor. These steps included performing ambient air quality testing at several locations including the landfill working face, the landfill perimeter, and at locations within surrounding neighborhoods. The testing revealed low levels of methane and H_2S in most locations, except around the leachate collection system cleanouts. With this information, the facility installed and began operating a pilot scale landfill gas collection system pulling gas from the leachate collection pipe cleanouts in June 2015. The facility conducted additional monitoring around the landfill and noted a decrease in methane emissions and odors around the perimeter following installation, and a larger flare was installed in January 2016. At this time, the facility also began planning for the installation of a landfill gas collection system, even though it was not yet required by NSPS requirements. Installation of a gas extraction wells occurred in 2016 and 2017.

In addition to these capital improvements, the facility added a vapor-phase odor neutralization distribution system along the perimeter of the facility in early 2016 and began using a mobile working-face odor neutralizing misting system. Operational changes included spraying incoming odiferous wastes with the odor neutralizing solution, using soil daily cover over the weekend (in lieu of spray-applied alternate daily cover), began using a more robust intermediate cover (placing a cement-fiber cover over the 12-inch intermediate/daily cover soil), and reduced the volume of WWTP sludge received for disposal. This combination of solutions has helped significantly reduce odor complaints at the facility; however, they come with additional capital and operation and maintenance cost for the facility.

Maryland: Following an anomalously wet year in 2018, a 77-acre commercial rubble (C&D) lined landfill began receiving substantial odor complains. The complaints were related to leachate H_2S, and the landfill had a good odor compliance record in the approximately 20 years of previous operations. Collected leachate was stored in tanks at the facility prior to discharge to a sanitary sewer. Initially complaints were along the sewer lines and near the pumping stations, but later the landfill facility itself began emitting detectable odors from the perimeter of the landfill cells. Monitoring at the facility indicated that gas concentrations were not over health standards, but the landfill operator acknowledged the odors were noticeable and problematic and they ultimately hired an international landfill gas consultant to help aggressively address the issue. On the recommendation of the consultant, improvements were made to

the existing gas flaring system, and ultimately the active gas extraction system was substantially redesigned. The interim gas collection system and flare were active beginning in February 2019, and the odor complaints essentially stopped at that time. However, further action was taken to improve the application of periodic and final soil cover and install a cap over completed portions of the landfill. Further review of operations and an evaluation of the waste streams led to the landfill stopping accepting waste from a C&D waste processer that was known to be rich in gypsum fines. To address the relationship between the odor complaints and leachate management at the facility, carbon filters were installed at the leachate tanks, and chemical neutralization of the leachate was initiated with the addition of oxidizers and regular pumping of the leachate level to reduce the anaerobic conditions. The perimeter venting of the leachate odors was addressed through the application of permanganate-infused geotextiles and mulch over an exposed gravel area where the venting was occurring. The resolution to the ongoing odor complaints and nuisance conditions was successfully achieved through changes in operations and rethinking the gas and leachate collection system operations. This has developed a system that can continue to be expanded as the landfill grows and is expected to continue providing adequate landfill odor control.

New York: Staff were receiving increasing odor complaints about a C&D landfill that also accepts industrial and commercial wastes along with contaminated soils and sludges. It was suspected that the increase in odor complaints was related to an increase in volume of C&D waste accepted for disposal. The facility had an existing passive landfill gas venting system in place, with vents installed at a frequency of approximately one per acre in closed landfill areas. An odor investigation determined that gas was being discharged from these passive vents, as well as from leachate collection riser and clean-out pipes, leachate drainage stone, leachate collection manholes (outside the lined landfill area), and off-site along the sanitary sewer line.

With this information, the facility employed multiple corrective actions resulting in reduced odors. These actions included:

- Changing the type of material used for daily and intermediate cover and eliminating the use of MSW ash as intermediate cover;
- Converting their passive gas venting system to an active gas collection system with a flare;
- Installing “stick flares” at known emission points (i.e., leachate cleanout pipes);
- Placing exposed geomembrane to prevent release of landfill gas from exposed drainage stone (coupled with horizontal gas collection pipes and stick flares);
- Using Acrulog™ to monitor for off-site odor impacts. The system would alert the landfill operator of any issues so they could take actions at the facility;
- Aggressive placement of intermediate cover and progressive final cover installation;
- Use of activated carbon canisters on landfill vents and manholes;
- Applying QuickSoil 2500 on the landfill surface in problem areas;
- Adding a site-specific weather station; and
- Pre-treating leachate prior to discharge to the sanitary sewer.

Tennessee: Recently a MSWLF was receiving numerous odor complaints from nearby neighbors. The facility was not subject to Air NSPS requirements and therefore, did not require a Gas Collection and Control System (GCCS). However, the Tennessee Department of Environmental Conservation’s Division of Solid Waste Management (DSWM) was able to work with the facility to improve landfill operations by increasing cover thickness on interim areas, providing better placement of daily cover in working areas,

minimizing working area footprint, sealing up leachate side slope risers and other cap perforations, installing an odor vapor / misting system, installing solar spark vent flares on leachate clean-outs that were generating landfill gas that was being released to atmosphere, and ultimately installing a voluntary GCCS. The DSWM also worked with the landfill to remove some odorous wastes from disposal at this landfill (transferred to another company operated landfill in a less densely populated area) and worked with the landfill to rearrange the disposal times of other odorous wastes so those wastes were being disposed during times when neighbors are at work, and there is plenty of incoming MSW to immediately cover the odorous waste. By addressing a number of small and medium odor sources, and ultimately installing a GCCS, odors have been significantly reduced in the community.

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Appendix A – Links to State Regulations

The following citations and regulatory links were provided by State representatives in response to the ASTSWMO odor control survey or were found by ASTSWMO Solid Waste Disposal and Conversion Task Force members during the research phase for this compendium. As these are links to various internet pages, links are subject to change.

State	SW Odor Citations	Solid Waste Regulations Link	Air Quality Odor Citation	Air Quality Regulations Link
Alabama		ADEM r. 335-13		
Alaska	18 AAC 60.233	18 AAC 60	18 AAC 50.110	18 AAC 50
Arizona		18 AAC 13		
Arkansas	Solid Waste Reg 22, various	AR Reg.22.		
California		27 CCR 14 CCR 7		
Colorado		6 CCR 1007-2 Part 1		
Connecticut	Sec 22a-209-7(n) Sec 22a-209-8	RCSA 22a-209-7	Sec 22a-174-23(a)(1)	RSCA 22a-174-23
Delaware	7 DE Reg 1300 (5.0) various	7 DE Reg 1300		
Florida	62-701.530(1)(a) FAC 62-701.530 (3)(b) FAC	62-701 FAC		
Georgia		391-3-4 (logon)		
Hawaii	HAR 11-58.1-15(b)(1)	HAR 11-58.1		
Idaho	IS 39-7412	IS 39-74 IDAPA 58.01.06		
Illinois	35 IAC 811.311(a)(3) 35 IAC 811.309(d)(5)	35 IAC 807-849		
Indiana	329 IAC 10-36-4	329 IAC 10		
Iowa	IAC 567-113.8(2)f	IAC 567-113		
Kansas	KAR 28-29-23(o) KAR 28-29-104(i)(3)(D) KAR-28-29-108(b)(2) KAR 28-29-3(jj)	KSA 65-34 & KAR 28-29		
Kentucky		401 KAR 30	401 KAR 53:010.4	401 KAR 53:010

State	SW Odor Citations	Solid Waste Regulations Link	Air Quality Odor Citation	Air Quality Regulations Link
Louisiana	LAC 33:VII.711.B.2.a.v	LAC 33:VII		
Maine	06-096-400.4.G	06-096-400 - 425		
Maryland	COMAR 26.04.07.03A	COMAR 26.04.07		
Massachusetts		310 CMR 19.000		
Michigan	Various	MAC R 299.49		
Minnesota	MR 7035.2815:11A.	MR 7001 and 7035	MR 7009.0080	MR 7009
Mississippi		11-Miss.-Admin.-Code-Pt.-4-Ch.-1		
Missouri	10 CSR 80-3(11)(B)&(D) 10 CSR 80-3(13)(B)6 10 CSR 80-3(C)	10 CSR 80	10 CSR 10-6.165	10 CSR 10-6
Montana		ARM 17.50, sub Chpts 11-14		
Nebraska	132 NAC 4.02	132 NAC		
Nevada		NAC 444.570		
New Hampshire		Env-Sw 100-2100		
New Jersey		NJAC 7:26		
New Mexico		NMAC 20.9		
New York		6 NYCRR Ch. IV, Parts 360-369		
North Carolina	15A NCAC 13B.0542 (f)(1)	15A NCAC 13	15A NCAC 02D.1801 15A NCAC 02D.1806(e)	15A NCAC 02D
North Dakota		NDAC 33-20		
Ohio	OAC 3745-27-19(B)(3) OAC 3745-27-01(N)(5)	OAC 3745-27, etc.		
Oklahoma		75 OAC 252:515		
Oregon		OAR 340-094		
Pennsylvania	25 PC 273.136	25 PC 271 to 25 PC 285		
Rhode Island	250-RICR-140-05-2.3.4	250-RICR-140-05-2	250-RICR-120-05-17.5	250-RICR-120-05-17
South Carolina	Reg. 61-107-19,Pt.II E.10. Reg. 61-107-19,Pt.IV C.7.	SC Reg. 61-107-19		
South Dakota		SDLC 74-27		
Tennessee		TEDC Rule 0400-11-01		
Texas	30 TAC 330.15 30 TAC 330.149	30 TAC 330		

State	SW Odor Citations	Solid Waste Regulations Link	Air Quality Odor Citation	Air Quality Regulations Link
Utah	UAC R315-303-4	UAC R315-303		
Vermont	CVR 12-036-003-6-503(b)(3)(A)	CVR 12-036-003-6		
Virginia	9 VAC 20-81-140.A.10	9 VAC 20-81	9 VAC 20-81-10	
Washington	WAC 173-351-200(2)(a)	WAC 173-351		
West Virginia	33 CSR 1-4.6.a.1.U 33 CSR 1-4.6.b.2.A	333 CSR 1		
Wisconsin	NR 514.06, WAC	Chapters NR 500 - NR 538	NR 429.03	NR 429
Wyoming		WS 35-11-101		

Appendix B - H_2S Odor Control Strategies

There are two strategies to control H_2S odors at MSWLFs that can be employed separately or jointly:

1) the generation of H_2S can be prevented by the prohibition or employment of modified disposal and landfill operational practices, and
2) the emission of H_2S can be controlled by the implementation of certain landfill practices.

Controlling the generation and limiting the emissions of H_2S can be undertaken employing short and long-term practices. The following sections summarize information presented in USEPA's Best Management Practices to Prevent and Control Hydrogen Sulfide and Reduced Sulfur Compound Emissions at Landfills that Dispose of Gypsum Drywall (2014).

Conditions Necessary for Development of Odors by C&D Waste

Hydrogen sulfide (H_2S) is a gas generated through the anaerobic decomposition of gypsum drywall (referred to in Section 3.2.4.3. as gypsum wallboard). H_2S is also known as hydrosulfuric acid, sewer gas, sulphuretted hydrogen, hepatic gas, sour gas and stink damp. H_2S is a poisonous, irritating, flammable, and colorless gas with a characteristic rotten-egg odor detectable by humans at low concentrations and a sweet odor at higher concentrations. H_2S is slightly heavier than air and may accumulate in enclosed, poorly ventilated and low-lying areas (USEPA, 2015).

H_2S is formed in the landfill environment via the reduction of sulfate (SO_4^{2-}) which is the primary H_2S generation mechanism in landfills. In addition to the presence of gypsum drywall in the C&D waste disposed in landfills, other factors contribute to the generation of H_2S in landfills:

- Moisture is needed to provide a medium for the growth of sulfate-reducing bacteria (SRB). Stormwater infiltration into the waste, the lack of a leachate collection and removal system, leachate recirculation, and the moisture content of the disposed waste all contribute to the moisture content of a landfill.

- The generation of H_2S requires organic matter as a substrate (food) for utilization by the SRB. The paper backing on drywall is sufficient to sustain the SRB. A MSWLF has a much greater amount of organic matter in comparison to a dedicated C&D landfill.

- Anaerobic conditions (a lack of oxygen) are necessary for the reduction of SO_4^{2-}into H_2S. This condition occurs in MSW and dedicated C&D landfills after the placement of subsequent lifts/layers of waste and soil cover.

- The pH and temperature conditions necessary for SRB to thrive typically occur in the MSW and dedicated C&D landfill environments. A pH ranging from 6 to 9 and temperatures ranging from 80°C to -1.8°C are necessary for SRB to exist (USEPA, 2015).

Laboratory experiments comparing SO_4^{2-}reduction in reactors containing fresh MSW with and without gypsum drywall indicated the concurrent production of methane (CH_4) and H_2S, and the reactors with added gypsum drywall produced sulfur emissions 10 times greater than the reactors without the added gypsum drywall (Fairweather and Barlaz, 1998) (USEPA, 2015).

Several factors may lead to the promotion in H_2S production in a MSWLF. It has been noted that the presence of degradable components in MSW results in the production of landfill gas, possibly resulting in a greater transport of H_2S through the landfill gas collection system or landfill surface. The reuse and/or disposal of C&D fines (RSM) at a landfill can lead to an increase in H_2S production. Also, the practice of leachate recycling/recirculation leads to an increase in landfill gas production including H_2S production.

Prevention of H_2S Odors from C&D Waste and Employing Best Management Practices

The prevention of odors attributable to H_2S formation begins with understanding the factors that cause the generation of H_2S. The preceding section identified factors necessary for H_2S generation. The following sections identify how some of these contributing factors can be addressed at a landfill to prevent or mitigate H_2S formation employing best management daily and other short term practices.

Controlling the Disposal and Reuse of C&D Waste Containing Gypsum Drywall

The most obvious means of preventing the generation of H_2S odor attributable to the disposal or reuse of C&D waste at a landfill is to prohibit its disposal and reuse. However, as discussed previously, the principal component of the C&D waste stream responsible for H_2S odor is gypsum drywall. Consequently, it may only be necessary to control or limit the content of gypsum drywall in the C&D waste stream. The practice of limiting/controlling the disposal and reuse of gypsum drywall at a landfill may be employed as a short-term practice until such time as other H_2S odor control strategies are employed as discussed later in this Appendix, or the limiting/controlling practice may be employed over the long term as an indefinite disposal ban.

Controlling Moisture Contact with C&D Waste

The key to minimizing H_2S generation in the landfill environment is controlling moisture contact with the C&D waste containing gypsum. This involves practicing sound daily landfill housekeeping operations. Daily operations which can minimize the contact of moisture with C&D waste, and therefore minimize H_2S generation, include minimizing the size of the daily active disposal fill face, grading the area adjacent to the fill face to minimize drainage into the active fill face, and the use of daily cover. Other short-term landfill operational practices that can be employed to minimize the contact of moisture with C&D waste include the proper operation and maintenance of the landfill environmental control systems, such as: the use and positive grading of intermediate and final cover, the timely repair of covered areas that have experienced settlement to prevent ponding and infiltration, and ensuring proper functioning of the landfill leachate collection and removal system and the landfill stormwater control system.

Reducing or minimizing the size of the daily active disposal fill face minimizes the area through which moisture can infiltrate through the waste mass. Likewise, grading the area adjacent to the daily active fill face or locating the daily active fill face so as to limit or prevent moisture from draining into the fill face can also reduce moisture contact with the waste mass. The use of daily cover encourages water runoff and assists in reducing moisture infiltration into the waste mass.

Similar to the use of daily cover, the use and positive grading of intermediate cover in those portions of the landfill which are not expected to receive additional waste receipts for an extended time period encourages surface water runoff and reduces infiltration, thereby limiting moisture contact with the waste mass. Timely repair of areas with intermediate or final cover that have experienced waste settlement encourages continued positive drainage, limits infiltration through the cover and contact of moisture with the waste mass.

The proper operation and maintenance of the landfill leachate collection and removal system can limit exposure of the waste mass to leachate. Likewise, the proper operation and maintenance of the landfill stormwater control system can effectively direct stormwater off of and away from the landfill, thereby limiting contact of moisture with the waste mass.

Controlling Sulfate Reducing Bacteria (SRB)

Limited laboratory research has been conducted on controlling or inhibiting the growth of SRB. USEPA notes that as of 2015, the use of bacterial inhibitors has not been examined on the field scale and further research is needed to assess the effectiveness of inhibiting SRB growth on H_2S production and the potential effect such an inhibition may have on the landfill environmental monitoring and control systems (USEPA, 2015).

Control of H_2S Odor Emissions from C&D Waste

In many cases, the generation of gas, and the resultant generation of H_2S, by a MSWLF, may be unavoidable. In such instances, methods and best management practices are needed to control and mitigate the H_2S odor emissions. As mentioned in regard to controlling moisture contact with C&D waste, the proper operation and maintenance of the primary landfill environmental control systems can assist in controlling and mitigating H_2S odor emissions. The primary control systems (leachate collection and removal, final cover and gas collection and control) work best in controlling odors when employed and operated as an overall combined and integrated system. In some instances, it may be necessary to augment the primary landfill environmental control systems or develop a secondary system to control emissions such as the application of a soil amendment or the use of odor neutralizers.

Leachate Management

H_2S contained in leachate volatilizes in accordance with Henry's law and it has been demonstrated that leachate can be a significant source of H_2S emissions (USEPA, 2015). Therefore, the control and prevention of pooling leachate and seeps on the landfill surface can contribute to reducing H_2S odor emissions. Control and prevention can be realized by the timely repair of landfill cover and the proper operation and maintenance of the leachate collection, leachate removal, and stormwater control systems.

Leachate storage systems such as tanks and ponds can also be significant sources of H_2S odor emissions.

Landfill Cover Systems

The installation of a final cover system with a low permeability layer can greatly assist in reducing H_2S odor emissions by preventing the conditions that allow moisture to infiltrate into the waste mass and preventing the release of odors to the atmosphere.

Landfill Gas Collection and Control Systems

Among other things, gas collection and control systems are installed in a landfill to control emissions to the atmosphere generated by the decomposition of the landfill waste mass. The installation of such a system in a MSWLF is commonly undertaken in order to comply with federal standards which mandate installation of a system upon the landfill reaching a certain waste capacity and emission rate threshold. However, such thresholds may not apply to a C&D landfill. Furthermore, while a C&D landfill may generate H_2S, waste receipts may not generate a sufficient amount of methane to allow for the operation of a gas collection and control system employing a destruction device. In such cases, a supplemental fuel may be needed to provide the minimum BTU content to combust the gas (USEPA, 2015). USEPA also

reports the combustion of landfill gas with high concentrations of H_2S can result in greater wear and tear on the destruction devices and increased SO_2 emissions from the destruction device.

Cover Soil Amendments

USEPA notes that natural soil cover has the properties to decrease the H_2S concentration gradient allowing time for H_2S to be attenuated or removed. In some cases, natural soils may need to be supplemented to improve the removal of H_2S. USEPA identifies a number of amendments that have been investigated in the laboratory and in the field. These include the use of ammonium nitrate fertilizer, coal ash, compost/biocover soil, concrete fines, fuller's earth, lime, steel tire shreds and metallic filter materials. However, it is cautioned that the effectiveness of these amendments is dependent on a number of variables such as the H_2S source concentration, atmospheric conditions and landfill conditions, all of which determine the amendments short versus long term effectiveness (USEPA, 2015).

Odor Neutralizers

Odor neutralizers are chemicals used to mask or mitigate an H_2S odor by reacting with the H_2S. The reaction either masks the odor or forms a non-odorous compound. Other agents attempt to control the odor by encapsulation, thereby blocking the odor from movement. The neutralizers are often sprayed onto or near the landfill working face or at the landfill site perimeter, depending on the odor source at the landfill. USEPA notes that odor neutralizers are considered temporary measures inasmuch as they do not prevent the generation of the odor.