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Key Landfill Emissions Research Needs & Knowledge Gaps

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Methane emissions from landfills have been noted by the EPA as being the 3rd largest source of anthropogenic emissions, with the top 2 being oil/gas and agriculture, respectively. Given the correlation between greenhouse gas emissions and climate change, the development of technologies to detect emission sources as well as to quantify total landfill emissions accurately is essential to the landfill industry. Detection of emissions sources is a crucial first step and can ensure a timely response to mitigating emissions. However, quantification is also critical for understanding the scale of emissions at different locations on a landfill. From a policy standpoint, the current landscape is increasingly moving towards quantification to assess emissions from a mass balance perspective and in corporate ESG reporting. This has become increasingly important in recent years as asset managers use sustainability reports (and the reported emissions in those reports) to assess whether or not to invest in companies based on ESG scoring matrices.

Historically, the basics of inventorying methane emissions from landfills consisted of a mass balance approach that accounts for three main quantities: methane generation, methane collection, and methane oxidation. Models have been used to estimate landfill emissions that are based on an initial estimate of how much methane is generated by the waste placed in a landfill. Because methane is created by microbes within the waste mass, these models are based on 1st order decay (FOD) kinetics developed in the microbiology field. Such models estimate methane generation based on waste composition and incoming waste mass. Emissions are then estimated by deducting the methane that is captured by the gas collection system and the methane destroyed via microbial methane oxidation that may occur in the cover system. Any remaining methane after this is assumed to be emissions.

In an effort to avoid using the FOD approach to model methane emissions, some methodologies were introduced to avoid and/or to supplement the FOD-based estimates such as the Collection Efficiency Assumption (CEA) model approach. However, landfill gas collection efficiency contains substantial variability in the values reported in the literature and by facility owners. Additionally, other models have been designed specifically as emissions models which do not attempt to estimate generation but instead focus on the parameters that result in emissions. Some work has been done to evaluate their efficacy, but for all models, the accuracy of the input parameters is critical.

In recent years, measurement advancements using technologies such as spectroscopy, light detection and ranging (LiDAR) have led to the ability to directly measure methane emissions rather than modeling them. Further technological progress on mounting measurement technologies to satellites, aircraft, drones and ground-based mobile equipment have provided multiple direct measurement strategies. While these direct measurement techniques hold tremendous promise, progress has been slow primarily due to: terrain/site geography, temporal changes in emissions profiles, variability in meteorology and operational changes. As a result, landfills remain one of the most challenging sources for accurately measuring emissions. With this said, the use of direct measurement still does not eliminate the need for models to estimate whole site emissions, since atmospheric models are needed to convert concentration measurements to infer whole site emission estimates.

Further, while models have the ability to generate an estimate of total site emissions on an annual basis, direct measurement technologies provide an estimate at a single point in time. Thus, an already challenging problem is layered by the frequency and duration of measurement. These issues must also be resolved to develop an accurate annual emissions estimate using direct measurement technologies. While not an exhaustive list of research needs, the 4 categories below along with their listed needs identify knowledge gaps, that if addressed, will improve the understanding of landfill emissions. These needs are listed in no particular order.

- Emissions and Atmospheric Modeling
- Uncertainties in Direct Measurement
- Emissions Inventories & Operational Practices
- Policy Analysis

Emissions and Atmospheric Modeling

Various models have been used to estimate landfill emissions. Some are already designated for use by policymakers or are used by facilities owners, while others are still in a development stage. Regardless, a key challenge with models is that most, if not all, are not fully vetted, and their accuracy has not been validated, as there is no standard to compare them against. In this respect, efforts to validate or ensure the most accurate data possible is used to populate model inputs are critical.

1. Development of methods or approaches to validate the accuracy of current models, including but not limited to:
    - HH-6/HH-8
    - SWICS
    - LandGEM
    - CALMIM
2. Development of new models or improving current ones to predict emissions (noted above or otherwise)
3. Confirming the accuracy of data used for model inputs and the relationship between these inputs and emissions. This could be done through efforts such as literature reviews, industry data aggregation, lab and field studies. Potential parameters include but are not limited to:
    - Landfill gas collection efficiency
    - Degradable organic carbon (DOC/DOCf)
    - Methane potential (e.g. Lo)
    - Decay rates (e.g. k)
    - Rate or levels of exceedances as it correlates to gas collection or emissions
    - Wellfield density as it correlates to gas collection or emissions
    - Waste composition and waste acceptance as they correlate to gas collection or emissions
    - Cover types as it correlates to gas collection or emissions
    - Waste in place

Uncertainties in Direct Measurement

Direct measurement of emissions is viewed as a critical component of advancing the understanding of emissions from landfills. Yet consistency and accuracy in using direct measurement technologies has been challenging.

4. Validating the accuracy and uncertainty of direct measurement technologies under a variety of landfill, site and meteorological conditions (e.g. controlled release studies, long term monitoring)
5. Determining which technology(ies) should be used given a particular set of site and meteorological conditions
6. Improving the accuracy of models used to convert direct measurements to whole site emissions.
7. Frequency of measurement (e.g. snapshot approach vs continuous measurement) and its influence on accuracy
8. Impact of wind speed on measurement accuracy
9. Influence of weather data sources and measurement location used with direct measurement strategies
10. Cost analysis of different technologies, frequency of measurement and tradeoffs between accuracy and cost

Emissions Inventories & Operational Practices

The creation of annual emissions inventories is important from both a policy making and corporate ESG standpoint. Establishing critical relationships between operational parameters and total annual site emissions is important, and allows site manages to make decisions more strategically while potentially providing a way to predict emissions from a given site.

11. Determining what emissions are intrinsic (i.e. inherent as part of landfill operations and are challenging or cannot be mitigated) versus fugitive (i.e. can be mitigated)
12. Evaluating which operating parameters provide the greatest emissions reductions (e.g. wellfield density, uptime, negative pressure, cover type, etc.)
13. Enhancement/development of strategies that minimize GHG emissions (e.g. vertical vs horizontal gas well designs, working face management, etc.)
14. Relationship or lack thereof between emissions and landfill gas collection efficiency
15. Identification of what fraction of annual emissions can be attributed to:
    a. Different areas of the landfill (e.g working face, closed sections and/or by cover type)
    b. Gas wellfield construction or repair related activities
    c. Temporal factors (e.g. time of day/year)

Policy Analysis

Current policies establish a variety of guidelines for monitoring and reporting of emissions from landfills. In some cases the policy is based on a substantial amount of scientific evidence, while in others, there is a lack of information. Further, some policies result in subjectivity or can create unintended consequences. A critical analysis of current and proposed policies can help guide reasonable policy making.

16. Performing a critical assessment/review of current EPA methods (e.g. Method 21) in terms of strengths, weaknesses, and whether these methods and the policies that rely on them achieve the stated/desired purpose

17. Evaluating the implications of current and proposed policy on emissions inventories, operational impacts, cost, etc. (e.g. HH-8)
18. Assessment of potential alternatives to current policies used to estimate emissions and compute emissions inventories that more accurately represent operational aspects and parameters that are more easily measured in the field
19. Evaluating the true cost of policy implementation in relation to the potential GHG reductions achieved, relative to other GHG (non-waste related) sources.