The Evolution of Methane Emissions Measurements at Landfills: Where are we now?

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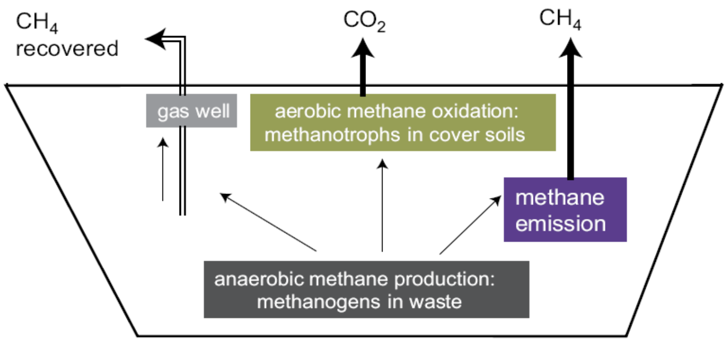
Agenda

- Background
- Emission Estimation Methods
- Monitoring Methods
- Flux Measurement Methods
- Closing Thoughts

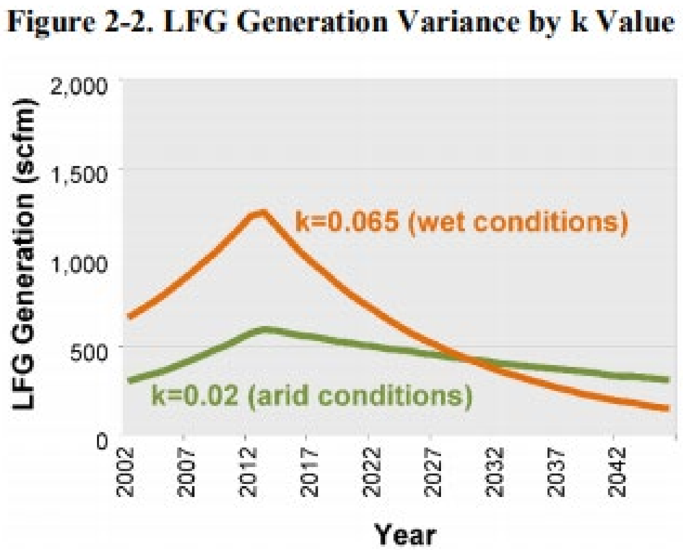
No Active GCCS

- Landfills without a GCCS must model emissions using:
  - First Order Decay (FOD) modeling
  - Non-FOD modeling



Simplified landfill Methane balance

LFG generation curves



FOD Models

- Date back to 1970: Scholl Canyon Model
- Intergovernmental Panel on Climate Change (IPCC)
    - o Solid Waste Disposal Model
- U.S. EPA
    - o LFG Emission Model (LandGEM)
    - o GHG Reporting Program (GHGRP)
- California Air Resources Board (CARB)
    - Landfill Methane Control Measure (LMCM)

Waste inputs in EPA's LandGEM

Year	Input Units *(Mg/year)*	Calculated Units *(short tons/year)*
0		
1		
2		
3		
4		
5		
6		
7		
8		

FOD Models: Critical Parameters

- Decay Rate: (k); rainfall dependent
- Methane generation potential: (DOC or L_0)
- LandGEM: Uses a single waste stream approach
- EPA GHGRP and IPCC: Can uses separate k and L_0 value for each waste type
- California variable Lo over time
- Methane oxidation applied

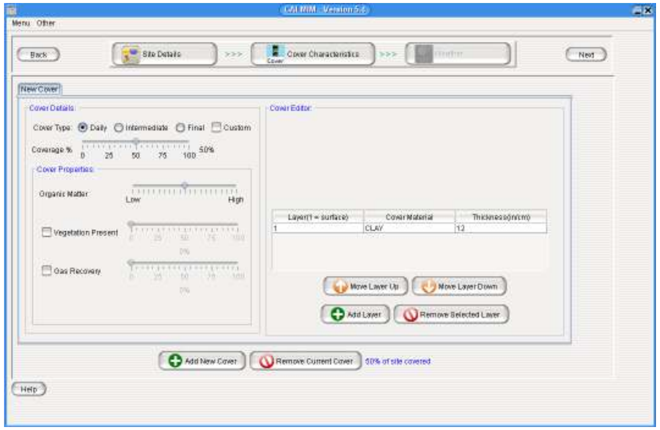
Critical FOD Model Parameters

Source	Waste Type	K (YR-1)	L_0 (M^3/Mg Waste)
LandGEM	MSW	0.02-0.04	100
GHGRP	MSW	0.02-0.57	101
	C&D	0.02-0.04	41
	Inert	0	0
	Food	0.06-.185	76
	Garden	0.05-.1	101
	Paper	0.04-0.06	203
	Wood and straw	0.02-0.03	218
	Textiles	0.04-0.06	122
	Diapers	0.05-0.1	122
	Sludge	0.06-0.185	0
	Industrial waste	0.08-0.1	76
California LMCM	MSW	0.02-0.057	68-110
	Greenwaste	0.02-0.057	63
	Sludge	0.02-0.057	25
IPCC	Food	0.1–0.2	76
	Garden	0.06–0.1	101
	Paper	0.05–0.07	203
	Wood and straw	0.02–0.04	218
	Textiles	0.05–0.07	122
	Nappies	0.06–0.1	122
	Sludge	0.1–0.2	25
	Industrial waste	0.08-0.1	76

Non-FOD Models

- CALMIM is the only utilized non-FOD model
  - o One-dimensional transport and oxidation model
  - o Recognized as Tier III methodology by IPCC
  - o Involves data not commonly collected (e.g., moisture)

CALMIM interface



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Sites with Active GCCS

- LFG Collection Systems provide flow and methane concentration data for:
  - FOD modeling with measured LFG collection
  - LFG collection with estimated collection efficiency

LFG collection system

LFG flares

FOD Model with GCCS

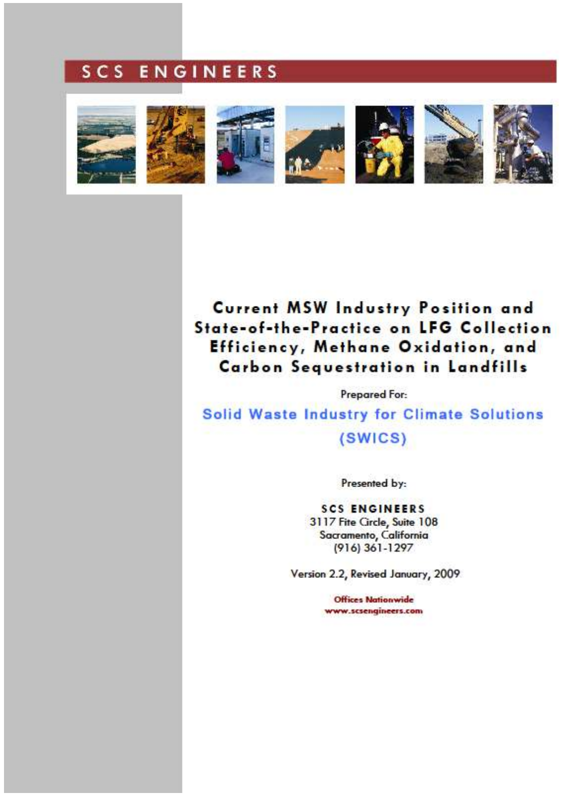
$$Emissions = (Generation - Recovery) x (1 - Oxidation)$$

- FOD model used to predict methane generation
  - If model under or over-predicts generation, then emissions affected accordingly
- **Recovered methane** measured as per GCCS equipment
- **Oxidation:** fraction of methane oxidized in landfill cover (applied to uncollected gas)
- **Emissions:** Difference between generation and recovery minus oxidation

Estimated Collection Efficiency

$$Emissions = \left(\frac{Recovery}{Collection\ eff} - Recovery\right) x \left(1 - Oxidation\right)$$

- **Methane Recovery** is measured
- **Collection Efficiency (CE)** is estimated
- Methane Emissions calculated from **both** factors
- SWICS and EPA determines overall facility CE
  - Derived from an area-weighted average collection efficiency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Current MSW Industry Position and State-of-the-Practice on LFG Collection Efficiency, Methane Oxidation, and Carbon Sequestration in Landfills

Prepared For:

Solid Waste Industry for Climate Solutions (SWICS)

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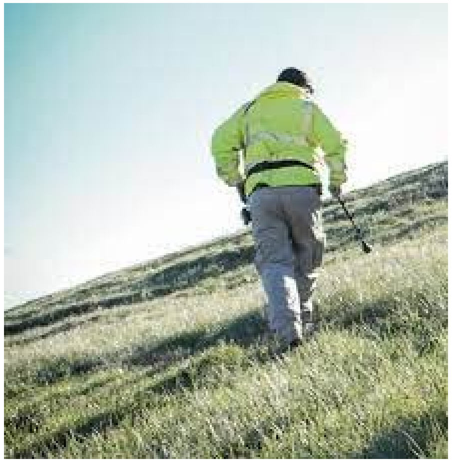
Surface Emission Monitoring (SEM)

- SEM: Using a portable methane meter near the landfill surface (EPA Method 21)
  - Instantaneous---serpentine path
  - Integrated---average over defined grid (50,000 sf)
  - Penetrations
- SEM derived from by EPA and state requirements
  - Quarterly monitoring
  - Requirements for corrective action and remonitoring
  - History dates back to early 1980's (SCAQMD)
  - Federal rules starting in 1996
  - Some states are more stringent



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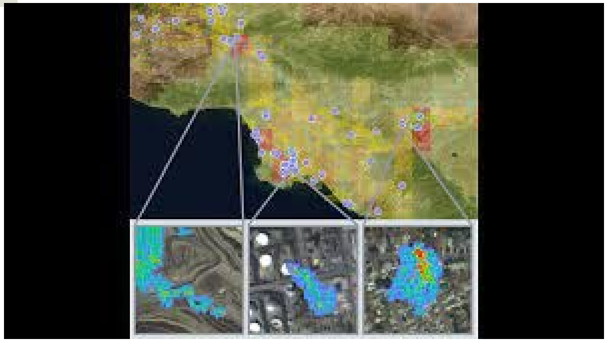
Ground or Low Altitude Imaging

- Devices: Infrared (IR), tunable diode laser (TDL), or hyperspectral cameras/scanners
- Screen for large methane emission points on the landfill surface
- Generally most devices not approved under Method 21
- Can give more holistic view of surface compared to SEM
- Hand-held or drone mounted

Satellite and Aerial Imaging



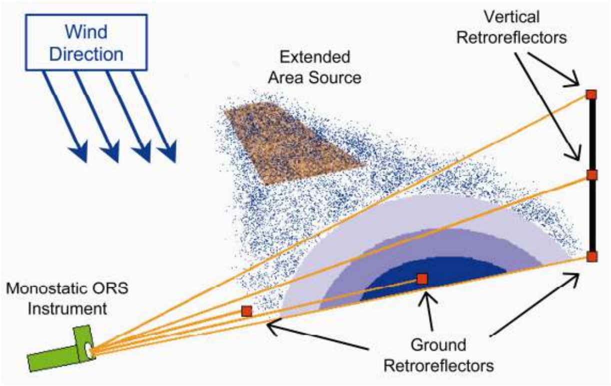
- High altitude or orbital imaging
- Devices: Satellites, aerial and orbital cameras
- Overall picture of methane emissions
- Companies: Carbon Mapper, Climate TRACE, Scientific Aviation, Methane SAT, CARB
- Most work is part of research programs (e.g., NASA JPL)
- Private companies starting make individual site contracts possible

Flux Chamber Testing

- Flux measured using chambers that sample a fixed area
- EPA: Method of scaling with required samples and locations
  - Number of scales required is impractical
- Alternative sampling strategies
  - Combination of SEM pre-screen and flux chamber siting
- Used in litigation and special projects
- Concerns about coverage

Ground-Level Plume Measurement

- Plume measurement uses optical sensor and reflectors to measure plume density
- Developed by EPA as Optional Test Method 10 (OTM 10)
  - OTM 10 now abandoned due to issues with real world application (e.g. repeatability, accuracy)

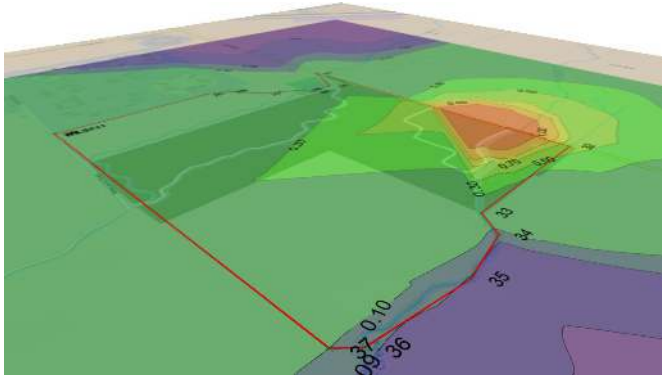


Micrometeorology

- Common stationary path method: Eddy covariance
  - Flux calculated from measured methane concentration
- Not required by regulation
  - Has been required for RD&D permits
- Technical and meteorological limitations
- Seeing more extensive use in research

Reverse Air Dispersion Modeling

- Uses air dispersion model (typically AERMOD or CalPUFF) with field methane data and local meteorology data
- Model in "reverse" to estimate methane flux
- Difficult source to model
  - Difficulties with hot spots
- Other limitations associated with monitoring methods



Tracer Correlation Studies

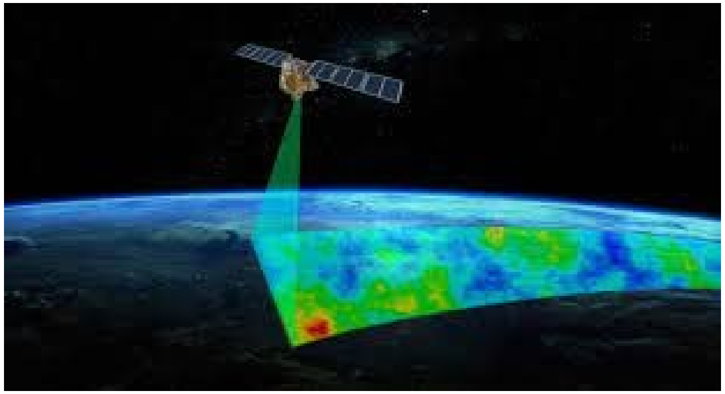
- Tracer gas sampling used to obtain atmospheric methane concentration
  - Known amount of tracer releases and concentrations downwind of tracer and methane
  - Correlation estimates methane release rate
- Methodology sensitive to meteorological conditions
- Technical advancements aid in regulatory acceptance of method
  - EPA application under OTM-33B
- Prominent in recent research studies

$$E_{gas} = Q_{tracer} \cdot \frac{\int_{Plume\ end\ 1}^{Plume\ end\ 2} C_{gas}\, dx}{\int_{Plume\ end\ 1}^{Plume\ end\ 2} C_{tracer}\, dx} \cdot \frac{MW_{gas}}{MW_{tracer}}$$

E_{gas}: methane emission rate (kg h^{-1}),
Q_{tracer}: tracer gas release rate (kg h^{-1}),
C_{gas} and C_{tracer}: cross-plume concentrations (ppb) above background,
MW: molecular weights,
x: distance across the plume.

Low and High Altitude Imaging Flux Estimation

- Calculate flux from observed concentrations
- Combine various parameters measured by aircrafts and satellites
- Key Issue: conversion from concentration to flux measurements
  - Due to accuracy of back-end algorithms for area source



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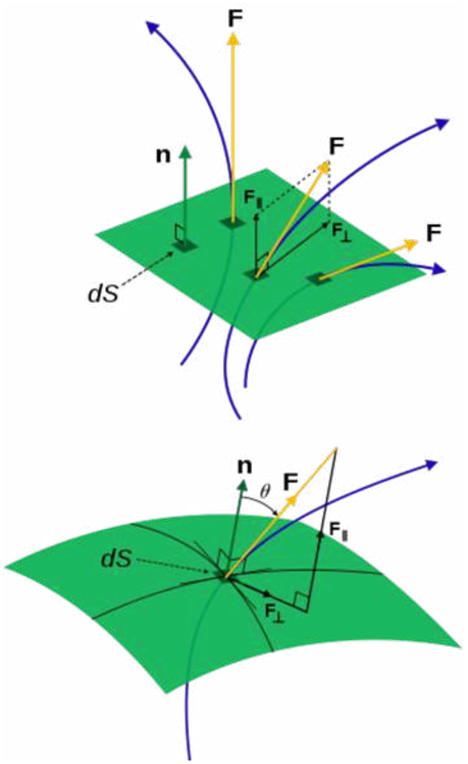
Hybrid Ideas in Development

- Cross- Evaluation of differing methodologies
  - SEM
  - Drones
  - Plus additional method done at same time
- Application can serve to validate or debunk new methodologies

Final Thoughts

- Despite technological developments, landfills still using FOD and SEM
- Variety of methods are being researched but none have risen to the top relative to flux
- Aircraft studies have suggested that methane emissions higher than being reported by industry
  - Increased scrutiny of landfills
- Drones are becoming common screening tool but can they be used for more?



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