Landfill Methane Capture Update from the Perspective of the Regulated Community*

By

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Meeting with ARB and CalRecycle Staff

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Four Part Scope

1. Recent direct measurement and modeling studies applied to CA Landfills (1:00-1:45).

2. Direct measurement studies conducted by the County Sanitation Districts of Los Angeles County (1:45-2:30).

3. Operator's perspective of recent activities and results in landfill methane capture (2:30-3:00).

4. Close with discussion of potential future meeting topics and areas for collaboration (3:00-3:15).

Part 1

(Based on: Walker et al. June 2014 Global Waste Symposium, Orlando Florida)

- Control Efficiency based on recent direct measurement studies for CA Landfills.
- Effects of coverage of gas system, oxidation, and relative and background short term emissions from working face and cover areas.
- Modeling of 113 landfills using ARB's online tool and measured collection.
- Conclusions with respect to the AB 32 Inventory and recent aircraft based measurement studies.

Methane Control Efficiency (COE)*

Index of methane emissions control including oxidation.

$$COE = (C + O)/(C + O + E)$$

$$O = (\%\ Oxidation \times E)/(1 - \%\ Oxidation)$$

C = Methane collected

O = Methane oxidized in cover soils

% Oxidation = Fraction of methane oxidized in cover soils

E = Methane emitted

* Collection , Abatement and/or Capture Efficiency terminology may not include Oxidation.

Direct Measurement Studies Applied to 5 CA Landfills under NSPS (OTM-10; Acetylene Tracer; Oxidation)

Goldsmith, C. Douglas, Chanton, Jeffrey, Abichou, Tarek, Swan, Nathan, Green, Roger, and Hater, Gary. (2012). Methane emissions from 20 landfill across the United States using vertical radial plume mapping. Journal of the Air & Waste Management Association (A&WMA), 62(2):183-197.

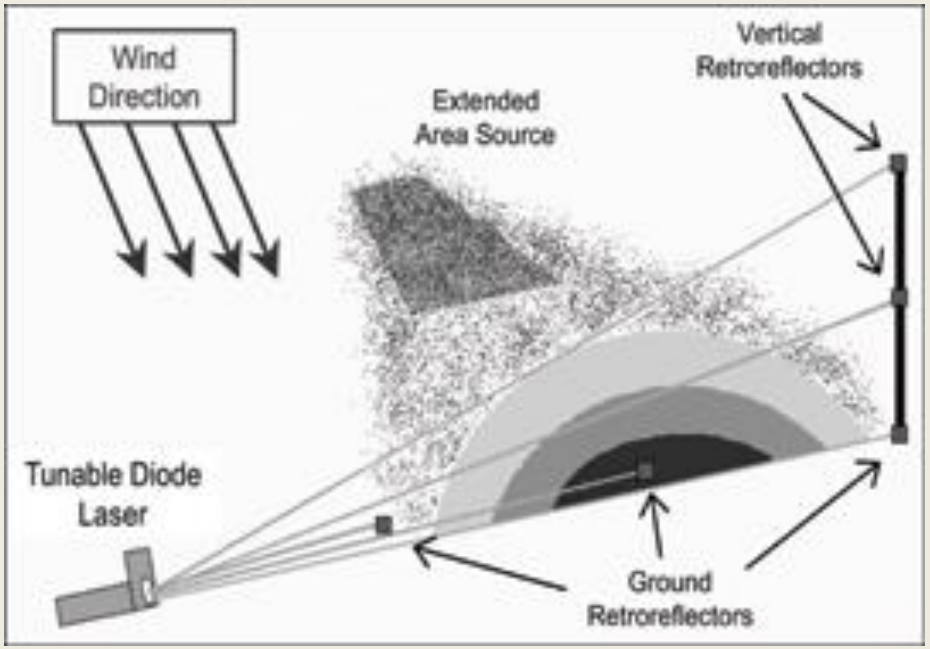
Chanton, J., T. Abichou, C. Langford, G. Hater, R. Green, D. Goldsmith and N. Swan. (2011). Landfill Methane Oxidation Across Climate Types in the U.S. Environmental Science Technology. 45 (1): 313-319.

Green, Roger B., Hater, Gary R., Thoma, Eben D., DeWees, Jason, Rella, Chris W., Crosson, Eric R., Goldsmith, C. Douglas, Swan, Nathan. (2010). Methane Emissions Measured at Two California Landfills by OTM-10 and an Acetylene Tracer Method. 2010 Global Waste Management Symposium.

Direct Measurement Methods Applied

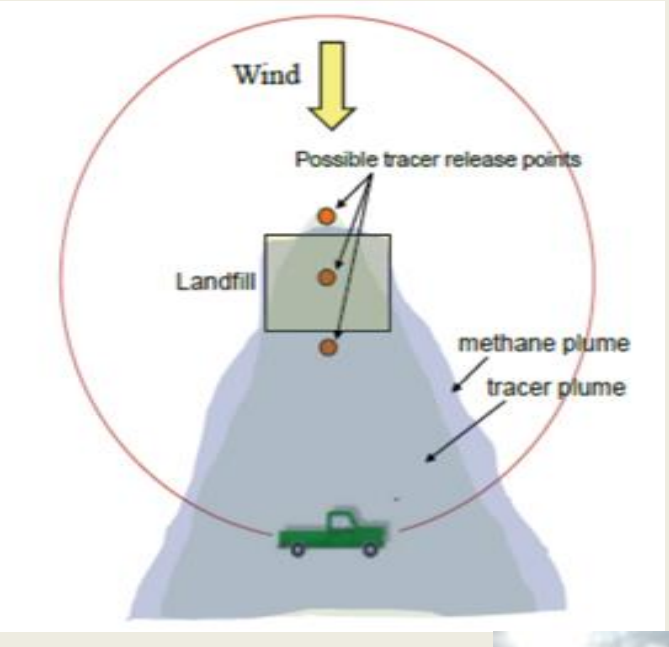
Description and comparative analysis from: Tracking Fugitive Emissions June 2012 (EREF funded research)
http://www.mswmanagement.com/MSW/Articles/17025.aspx

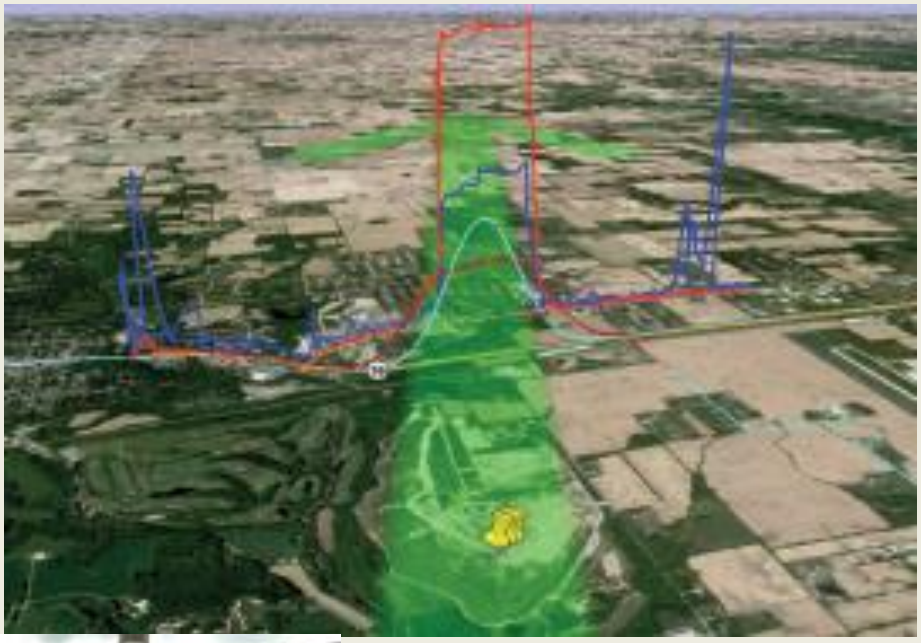
1. Vertical Radial Plume Mapping (VRPM) USEPA OTM 10.



Direct Measurement Methods Applied

2. Tracer Gas Correlation Using Mobile Spectroscopy





Other Direct Measurement Methods Applied (Part 2 Presentation)

- Flux Chambers (Dynamic and Static)
- ISM/ISC: air dispersion model coupled with Integrated Surface Methane (ISM) concentration data

CA Facility Characteristics

Facility:	CA1	CA2	CA3	CA4	CA5
Annual Precipitation:	25 inches	20	14	14	7
Geomorphic Province:	San Francisco Bay	Coast Range	San Francisco Bay	Coast Range	Mojave Desert
Waste Footprint:	200 acres	65	115	235	80
Waste-In-Place (million tons):	13.5	6.1	13.5	44.1	6.2
Annual Methane Collected (scfm):	1225	685	939	2422	201
Landfill Gas Collection System:	Vertical and Horizontal Wells, LCRS, Vertical Well Risers				

Facility Characteristics (cont.)

Facility:	CA1	CA2	CA3	CA4	CA5
Final Cover %:	0% (of total footprint area)		33%	10%	0%
Intermediate Cover %:	98% (of total footprint area)		65%	88%	98%
Daily Cover %:	2% % (of total footprint area)				
% Coverage Gas Collection:	98+% (of total footprint area)				
Leachate recirculation:	No	1-5 million gal/yr	No	1-2.6 million gal/yr	No
Other Design-Operation aspects:	Unlined (90%); Shallow GW-Inward Gradient; High % Sludge	Composite lined (75%); Canyon Fill	Unlined; Shallow GW-Inward Gradient	Composite-lined (50%); Canyon Fill	Unlined (90%); Negligible Leachate

Measured Flux/Emission Rate (grams/m^2/day) *

From: (Goldsmith et al. 2012) and (Green et al. 2010)

	Aggregate	CA1	CA2	CA3	CA4	CA5
OTM-10 (Jan-Feb 2009)			9.58	6.04 (final cover); 10.3		3.96
OTM-10 (Jun-Oct 2009)		4.64; 19.3	32.15	8.18	14.45; 9.48	0.9
Tracer (Oct 2009)		8.5; 7.9; 5.4			7.5; 14.3; 13.1	
Mean:	**10.1**	9.13	20.87	8.17	12.83	2.43
Stdev:	**4.3**	5.87	15.96	2.13	2.32	2.16

* All intermediate cover except 6.04 final cover for CA3

Measured % Oxidation

- Best assessment of mean from all 20 landfills studied is 37.5% (± 3.5%). (Note 38% overall from SCS November 2012 compilation of 47 published studies)
- Summary for the 5 CA landfills of mean of two methods from flux boxes (mid-point isotopic and non-isotopic fractionation) Table 1 Chanton et al. (2010).

	Aggregate	CA1	CA2	CA3	CA4	CA5
Methane Oxidation:	**41%**	52%	54%	27%	28%	34%

Landfill Methane Control Efficiency (COE)

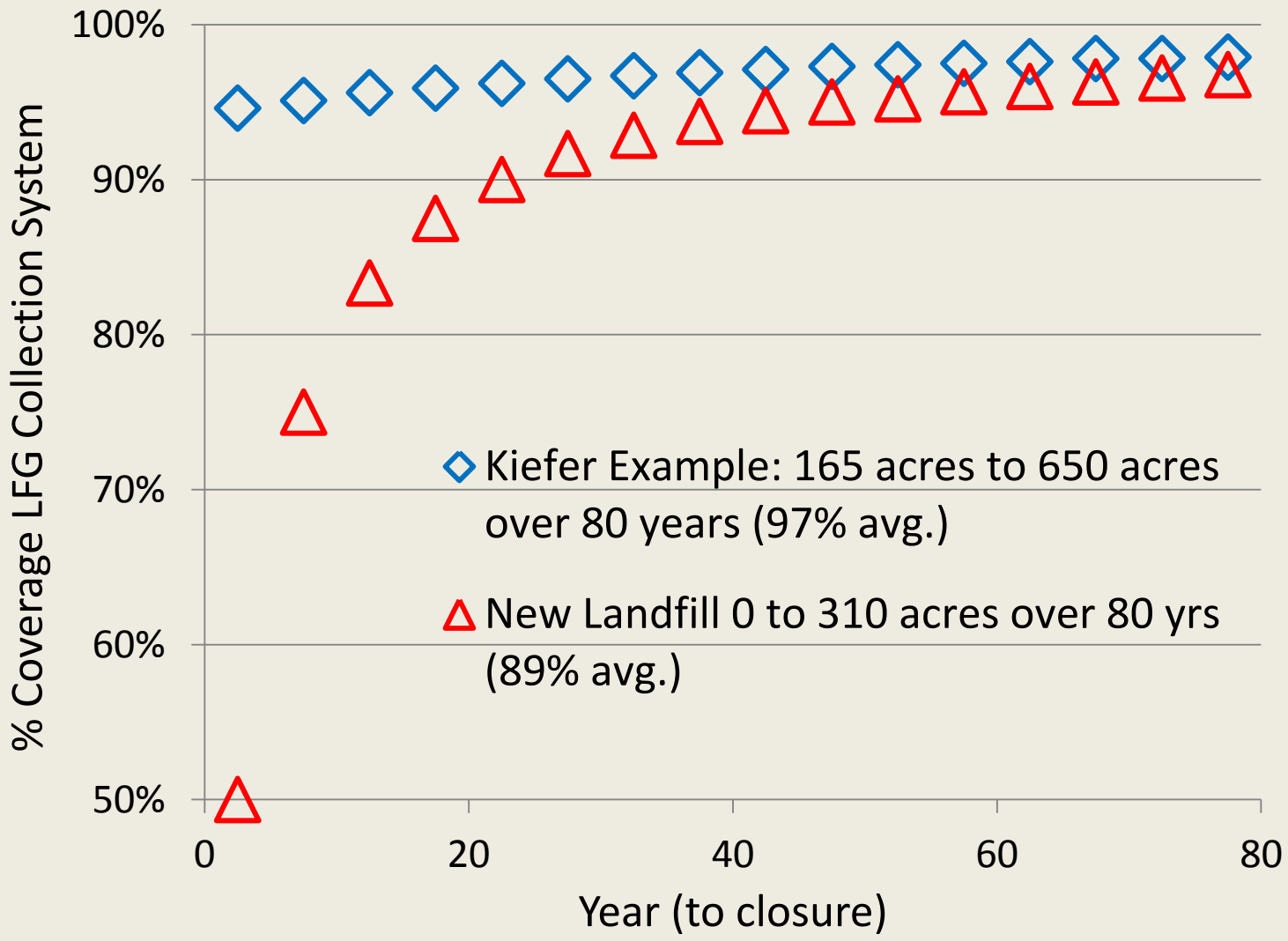
	Aggregate	CA1	CA2	CA3	CA4	CA5
Methane Collected (C) (study period year)	5,472 scfm	1,225	685	939	2,422	201
C (Megagram MG/year)	55,150	12,346	6,904	9,464	24,410	2,026
Measured Methane Emissions (E) (MG/yr) applied to waste footprint	10,677	2,698	1,849	1,388	4,454	287
Oxidation (O) (MG/yr) = (% O x E) ÷ (1-% O)	7,372	2,775	2,071	524	1,765	150
COE = (C+O)/(C+O+E)	**85% (80-91% ± 1 SD)**	**85%**	**83%**	**88%***	**85%**	**88%**

* COE= 91% for final cover measurement applied to entire footprint.

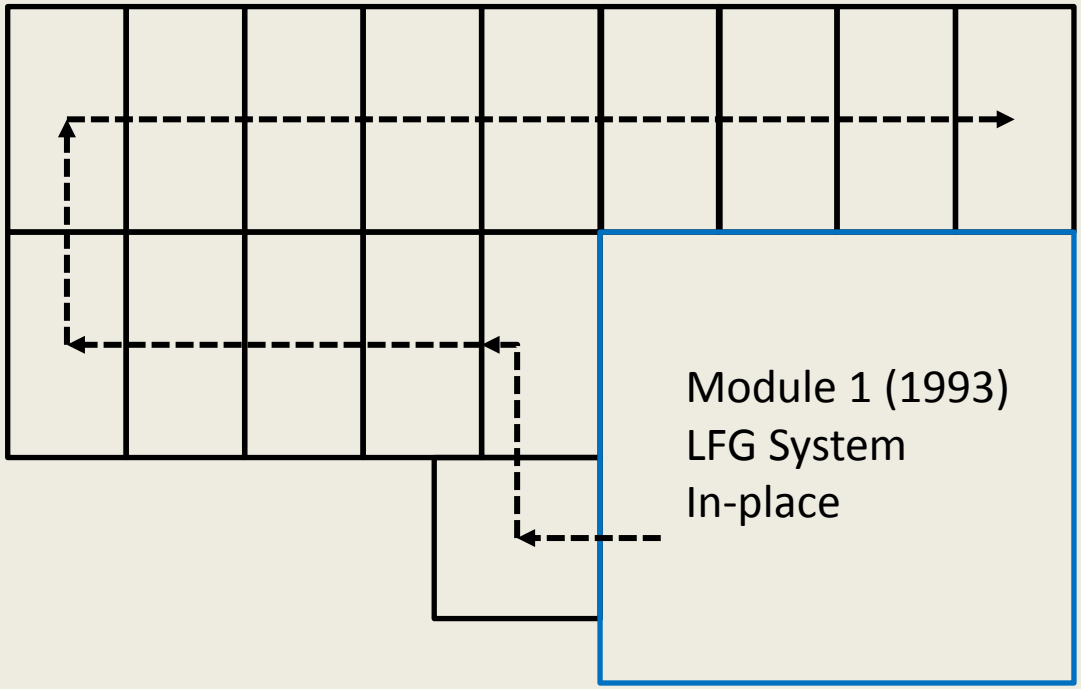
Extent Coverage of LFG Collection System

- Average age of waste in new modules under NSPS will be <2.5 years and for CA dry conditions methane generation is relatively slow.
- Horizontal wells (with or without vertical wells) and collection from LCRS provide interim coverage as module fills until full system in-place.
- Adjustment of adjacent wells and well risers maintain collection when filling over older waste.
- Cover maintenance important based on soil type.

Minimum % Coverage of LFG Collection Systems- NSPS Applicable Area Fills 89-97%



Conceptual Area Fill Example Based on Kiefer Landfill :



- 5- year Modules added until closure in 2073.
- LFG System expanded as each module is filled.

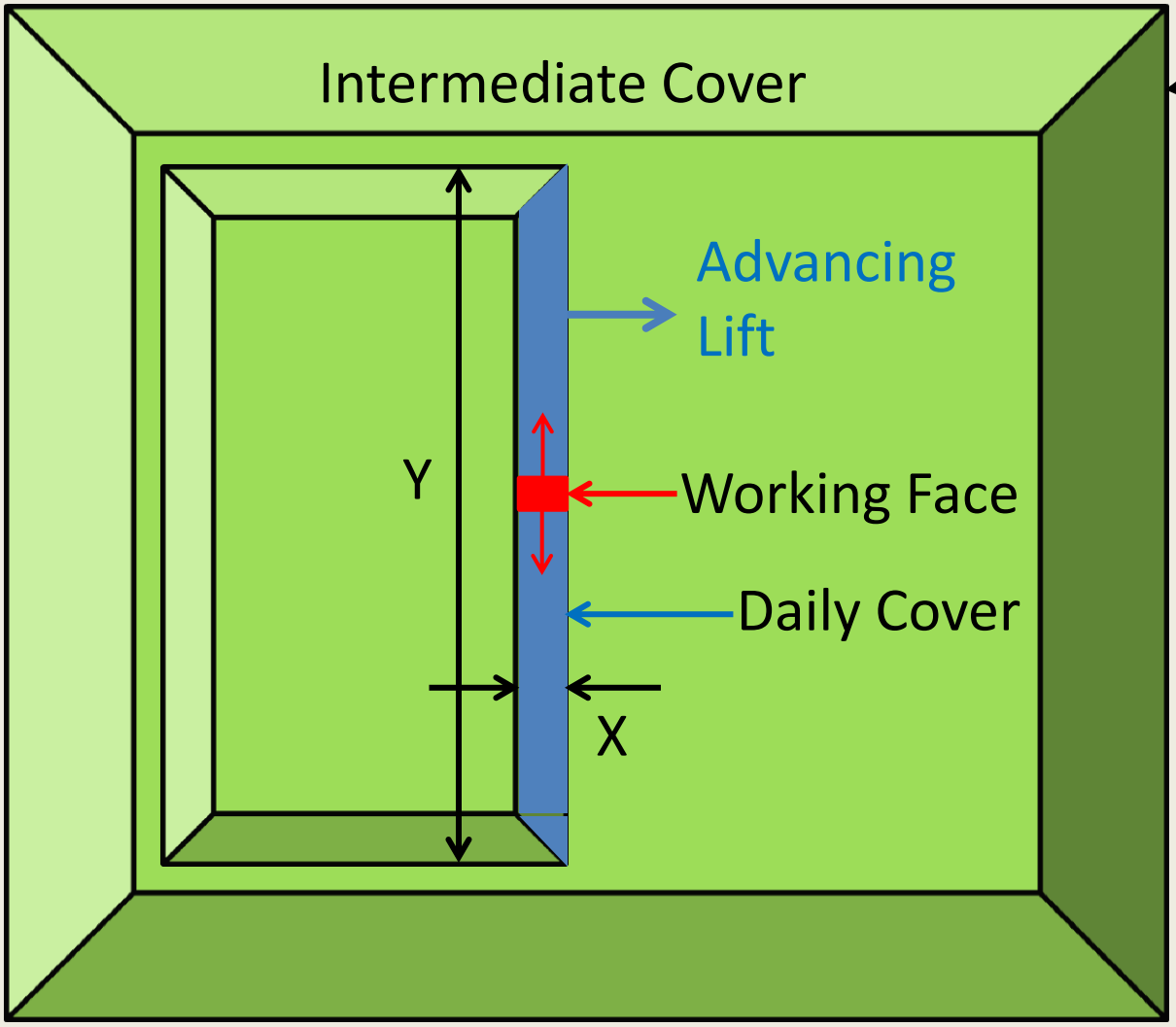
Conclusions: Extent LFG System Coverage

- High effective coverage achieved prior to complete filling of NSPS applicable modules.
- The 5 landfills meet estimated 98+% coverage. Effect on COE of 98+% coverage is <-1% and for 95% coverage effect on COE is <-2% (assumes very conservatively not covered COE is 0%).
- Similar coverage expected other large compliant NSPS CA LFs with exception during early landfill life (not applicable to smaller non-NSPS LFs).

Effect on COE for Variation in Methane Oxidation is Negligible

- Results for the 5 landfills: lowering from 41% to 10% oxidation has negligible effect on aggregate COE from 85% to 84+% (<-1%).
- Effect would be more significant for lower Collection Efficiency (CE): for 50% CE and 50% oxidation COE is 67%; for 50% CE and 10% oxidation COE is 53%.

Relative Area of Working Face, Daily Cover, and Intermediate Cover



Developed Footprint

X- Slope Length of Advancing Lift

Y- Advancing Slope Width

Cover Areas Based on Optimum Cell Size

Bolton, Neal. (1995). Calculator:
http://www.blueridgeservices.com/tools/index.html

Working Face (Y sf) = $194.6x^{0.5622}$ (X = Daily Tonnage)

Landfill	**X** (Daily Tonnage)	**Y (**Working Face (sf))	Working Face (acres)	Developed Footprint (acres)	**% Working Face to Developed Footprint**
CA4	4,158	21,071	0.48	235	**0.21%**

Daily Cover (sf) = Y * SQRT(developed footprint)

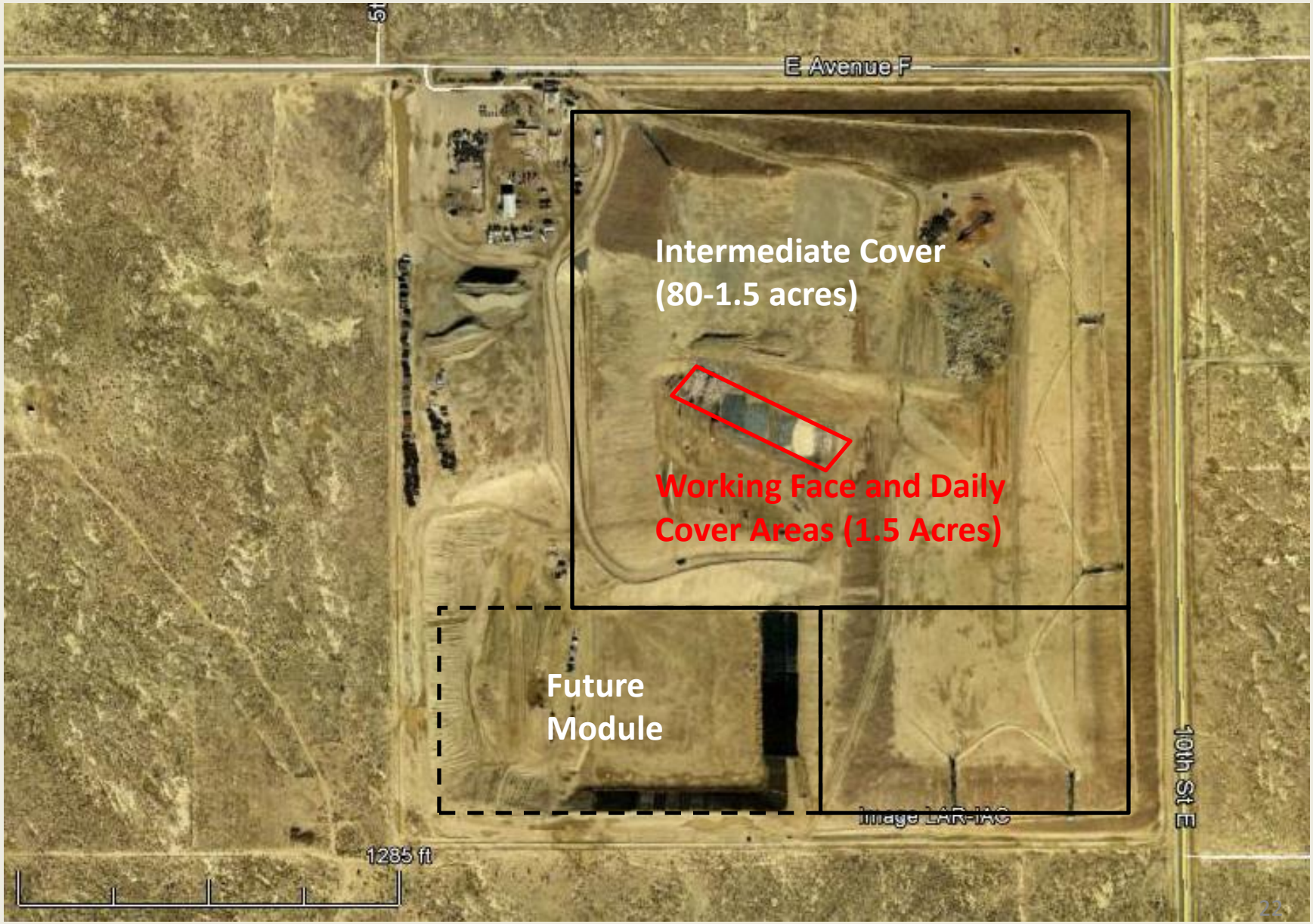
Slope Length Advancing Lift (Y ft) = $4.0717X^{0.337}$ (X = Daily Tonnage)

	Y	SQRT Footprint (ft))	Daily Cover (sf)	Daily Cover (acres)	**% Daily Cover to Footprint**
CA4	68	3,199	215,982	5.0	**2.1%**

Validation Working Face Area is Minimal

- CalRecycle analysis of 2010 google earth™ images for 85 landfills verified working face size is minimal (2.7x mean Bolton equation with SD 1.63).
- Total statewide working face for 2010 is 19 acres; extrapolated from google earth™ is 51 acres.
- Working face normally only partially exposed during operating hours and covered by evening.

CA5 Google Earth ™ Image and Footprint



Relative Cover Area Methane Emissions

- Flux relative to intermediate cover for 20 landfills across US (from Goldsmith et al 2012):

	Working Face	Daily Cover	Intermediate Cover	Earthen Final Cover*
Average Factors	2.6	1.6	1.0 (41.5 gm/m2/d)	0.5
Highest Factors (Semi-Arid)	23	3.0	1.0 (3.7 gm/m2/d)	0.7
*Geomembrane based at one site: 0.09 g/m^2/d (factor >0.02)				

- Negligible effect on COE of -0.25% to 1.0% if applied to CA1-CA5. Consideration of background methane from anaerobic fermentation will further reduce effect.

Conclusions- 5 Landfills Direct Measurement

- Significantly higher level of methane capture achieved (85%) than 77.5% default. COE is 91% if the single CA3 final cover measurement is applied to the entire footprint.
- Effect on COE is negligible for oxidation, coverage of LFG system, and working face-daily cover areas.
- Measured emissions 35% less than Modeling Tool and 39% less for default COE applied to measured collection (Year 2009).

Conclusions- 5 Landfills Direct Measurement

- Results representative of CA large NSPS fully compliant facilities and prior to implementation of the LMR.
- Results not representative of smaller non-NSPS landfills, nor landfills with compliance issues.
- Oxidation is significantly higher than 10% default (note new USEPA default protocols GHG Reporting: (http://www.epa.gov/ghgreporting/reporters/subpart/hh.html).

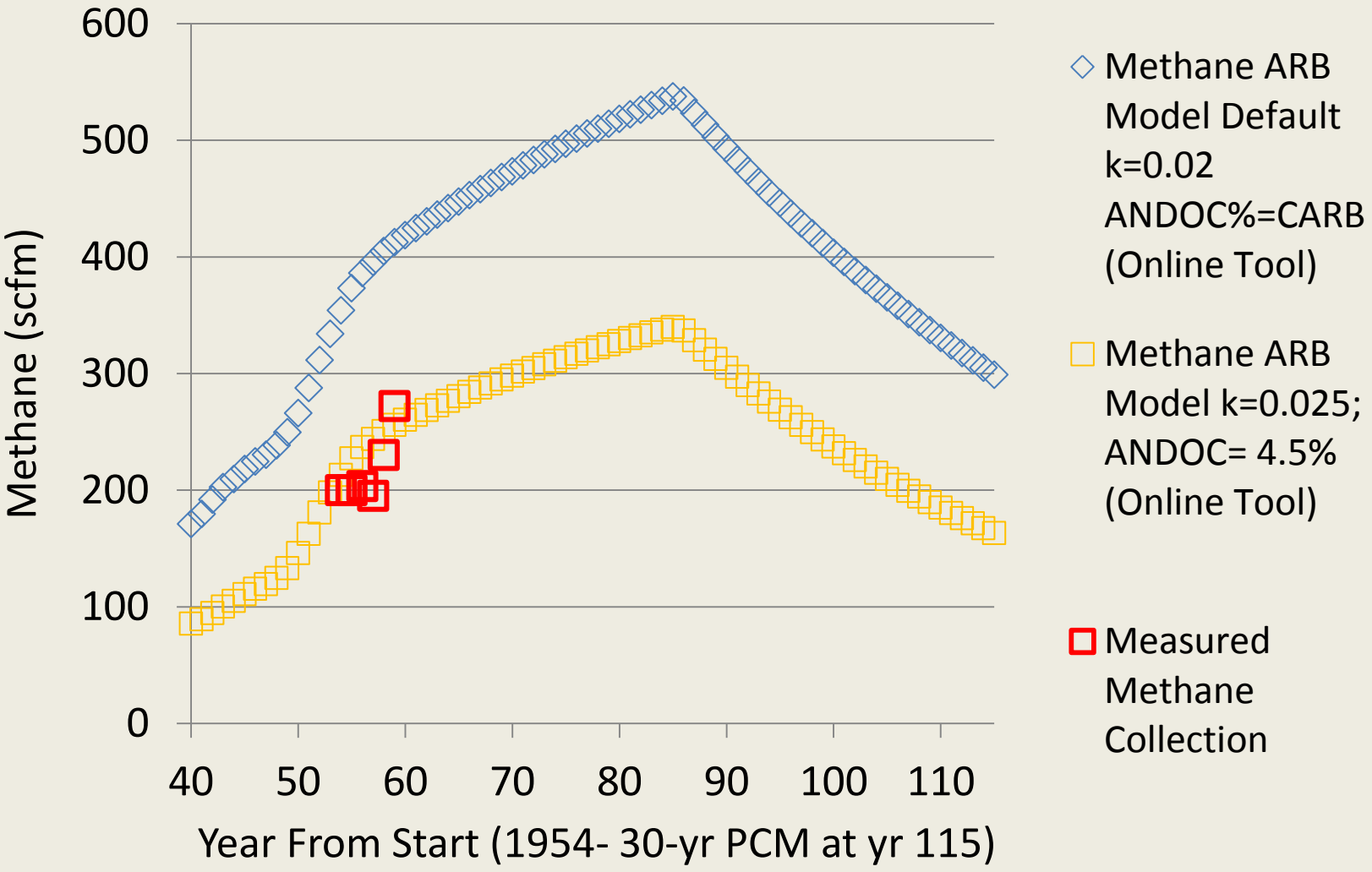
Additional Modeling

- ARB First Order Decay modeling tool for compliance with the LMR: http://www.arb.ca.gov/cc/landfills/landfills.htm; Methane collection/site info adjusted from: http://www.calrecycle.ca.gov/Actions/PublicNoticeDetail.aspx?id=498&aiid=483
- Applied to 5 landfills from this study and 113 other CA landfills (52 closed and 61 active) for Year 2010.
- Waste-in-Place (WIP): 90% of total CA 2010 WIP;
- NSPS is 80+% total WIP and LMR >0.45 MT is 88%.

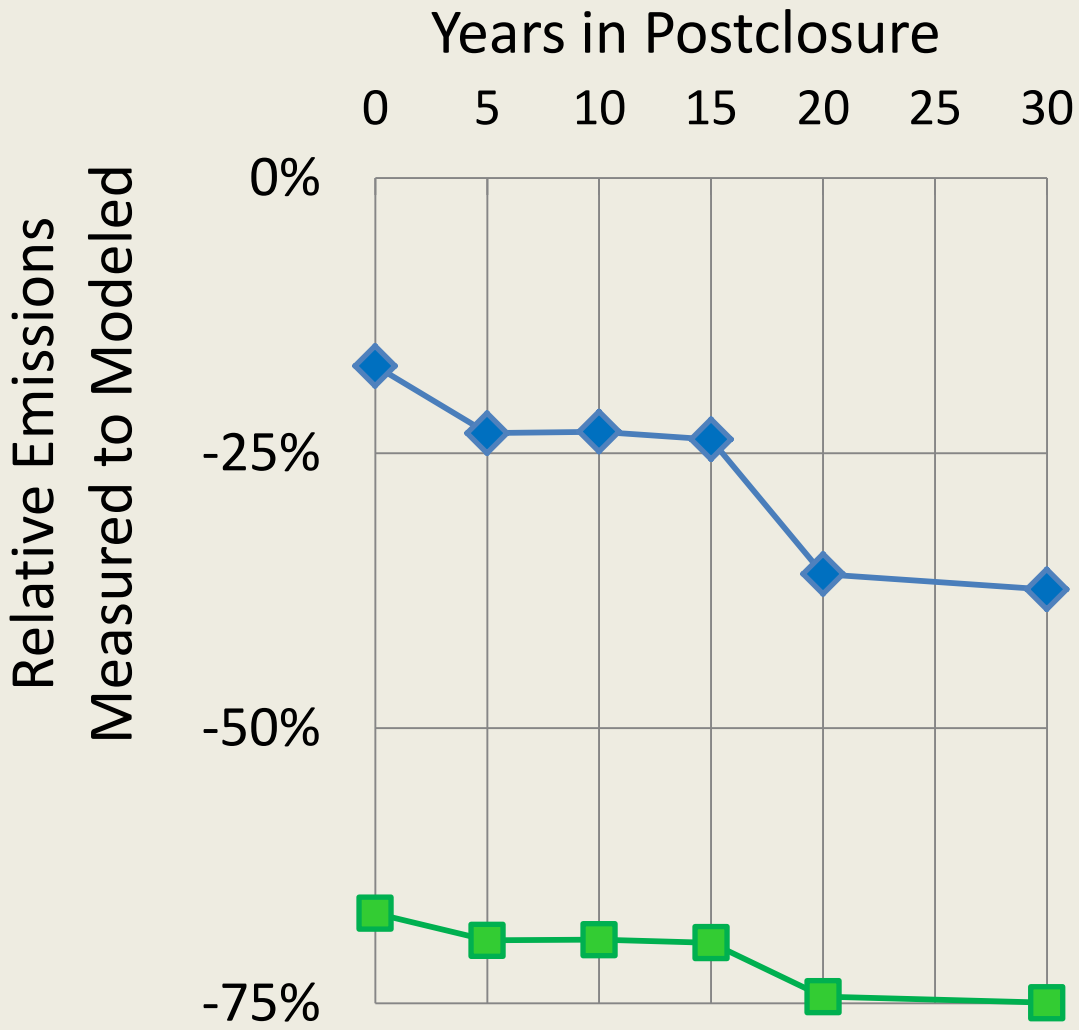
Conclusions: Modeling 118 Landfills

- Emissions from COE applied to measured collection relative to Model (overall similar but higher for active and lower for closed):
  - Apply COE Default 77.5%: **+7%** (+16% active; -17% closed).
  - Apply COE from 5 studied landfills 85% (active) and 91% (closed): **-44%** (emissions reduction to 2020 high end of LMR -24-47%; 2-4 MMTCO2$_e$ from 8.5 baseline).
- Other major conclusions:

Category of Arid Landfills (e.g., CA5) with Effective Methane Potential (ANDOC%)



Methane Declines More Rapidly With Time After Closure Than Models Predict

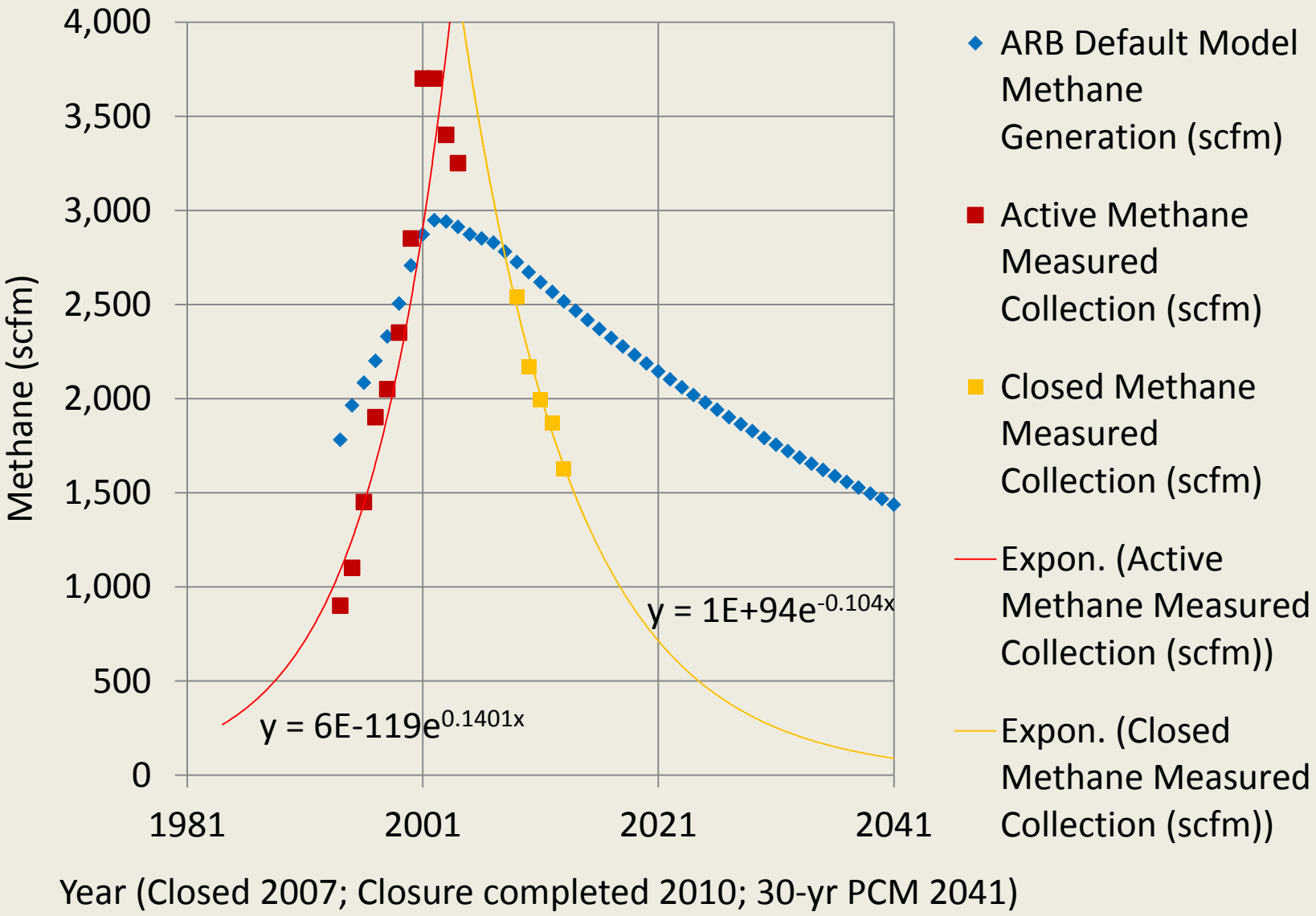


Note: Drop appears more pronounced for younger closed Subtitle D landfills vs. older closed landfills

Default 77.5% COE

91% COE

Example: Closed Site 19-AR-0008



Measurements Based on Research Aircraft

(Peischl, J. et al. 2013. Quantifying sources of methane using light alkanes in the Los Angeles Basin. Journal of Geophysical Research: Atmospheres, Vol. 118, 4974-4990)

	Puente Hills LF 19-AA-0053	Olinda Alpha LF 30-AB-0035
Collected and Combusted (in scfm 2010 from CIWMB)	9,454	4,194
CH4 in MG/yr Collected and Combusted	95,283	42,269
CH4 in MG/yr Emissions (Aircraft)	34,998	12,501
Estimated Emission Rate (Aircraft)	35.9 gm/m2/day	20.2 gm/m2/day
Assume Methane Oxidation %	38%	38%
Methane Oxidation in MG/yr	21,451	7,662
Collection Efficiency	**73%**	**77%**
Control Efficiency (COE)	**77%**	**80%**

Preliminary Conclusions Aircraft Based Methane Measurements

- LACSD (Part 2) determined lower emission rate/higher collection efficiency for Puente Hills (4.8 gm/m2/day and 95.9% vs. 35.9 gm/m2/day and 73% aircraft).
- We conclude the aircraft measurements are a higher bound and actual emissions from landfills are lower because of limited resolution to remove other potential sources of methane.
- Atmospheric conditions (e.g., inversion) may also affect background methane resulting in bias toward higher emission rates (related study in progress).

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Part 1. Questions/Discussion?

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Meeting with CARB and CalRecycle Staff
August 6, 2014