Contributions of Academic Research to the Diagnosis and Management of Elevated Temperature Landfills

What did we learn and was it helpful?

Morton Barlaz

Department of Civil, Construction, and Environmental Engineering
North Carolina State University

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Strategic Partner EREF

How research progressed

- Model development
- Study exothermic pyrolysis in the lab
- Model Parameterization
  - Hydration, carbonation, corrosion, methane generation at elevated temperature
- Field test to carbonate ash
- Look up tables
- User-friendly model

Approach

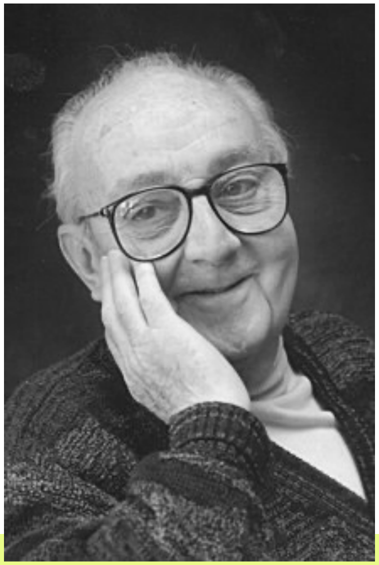
- Start Simple: Batch Reactor Model to quantify the importance of biotic and abiotic heat sources
- Build Complexity: Transient 3-D finite element model to describe spatially dependent heat and mass transfer

Why a model?

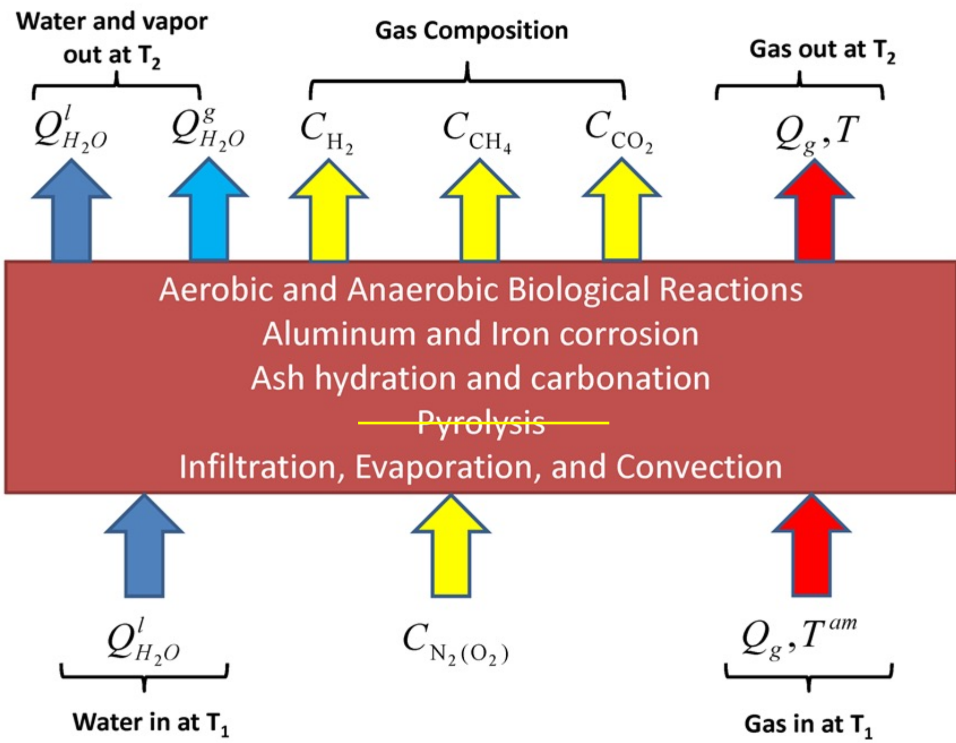
- A model forces the developer to describe every aspect of a process
  - helps to identify what is known and unknown
  - prioritize filling critical information gaps/sensitivity analysis

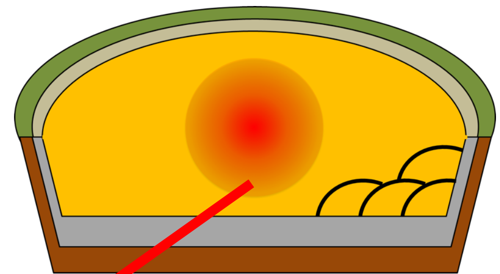
All models are wrong but some are useful

George Box, 1978



The Batch Reactor Model

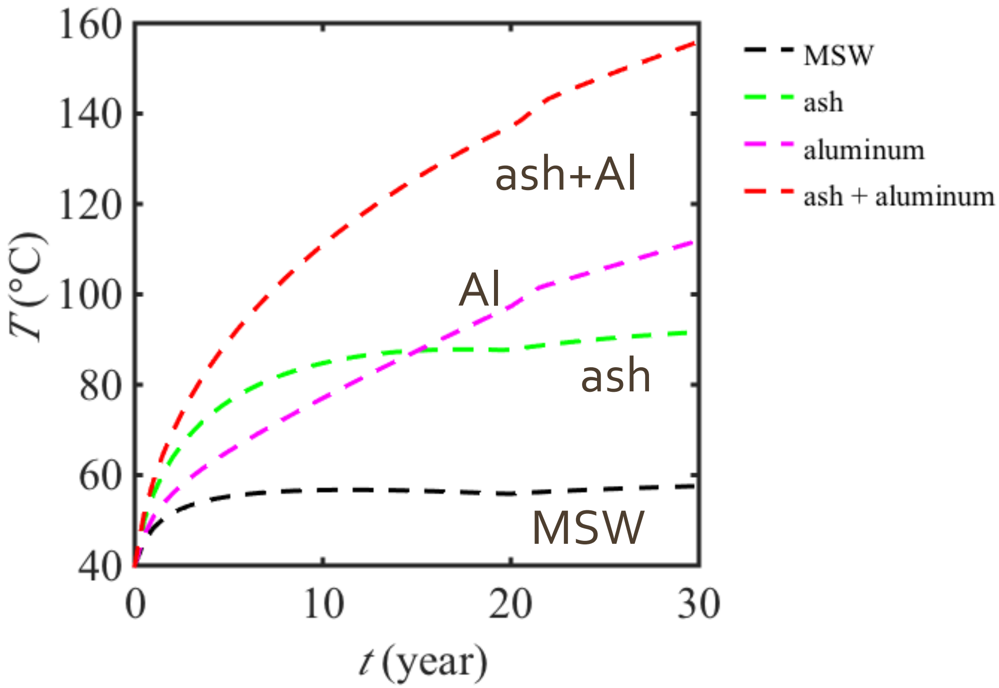




- single addition of MSW
- perfectly mixed closed unit
- biotic and abiotic reactions
- liquid and gas flux into and out of the unit
- uniform temperature

The Batch Reactor Model

Dominant heat generating reactions



- Important reactions: ash hydration and carbonation, metal corrosion
- Heat loss mechanisms (convection, infiltration, evaporation)
- 100% Al availability for corrosion
- 10% ash content, allow hydration and carbonation

process research on rates and extent

Predicted Temperatures for Burial of Ash at Year 20

	Look-Up Tables		% of Ash in Landfill; balance is MSW	0% [a]	10%	20%
% Ca in ash[b]	% initial $CaO/Ca(OH)_2$[c]	% hydrated[d]	% carbonated[e]			
15	100/0	100	50	146	155	176
			100		161	191
	0/100	0	50		149	154
			100		154	171
20	100/0	100	50		161	192
			100		170	212
	0/100	0	50		151	159
			100		158	185
25	100/0	100	50		168	208
			100		179	234
	0/100	0	50		152	165
			100		164	199

[a] The base case – MSW only

[b] % Ca data are converted to CaO or $Ca(OH)_2$

[c] % initial $CaO/Ca(OH)_2$ – 100/0 means all Ca is in the form of CaO and 0/100 means that all reactive Ca-containing ash is in the form of $Ca(OH)_2$.

[d] % hydrated – 100 %: all CaO hydrated in the landfill; 0 %: all hydration complete before burial

[e] % carbonated – 50%: 50% of the generated or initial $Ca(OH)_2$ undergoes carbonation in the landfill; 100%: of the generated or initial $Ca(OH)_2$ undergoes carbonation in the landfill

The Batch Reactor Model

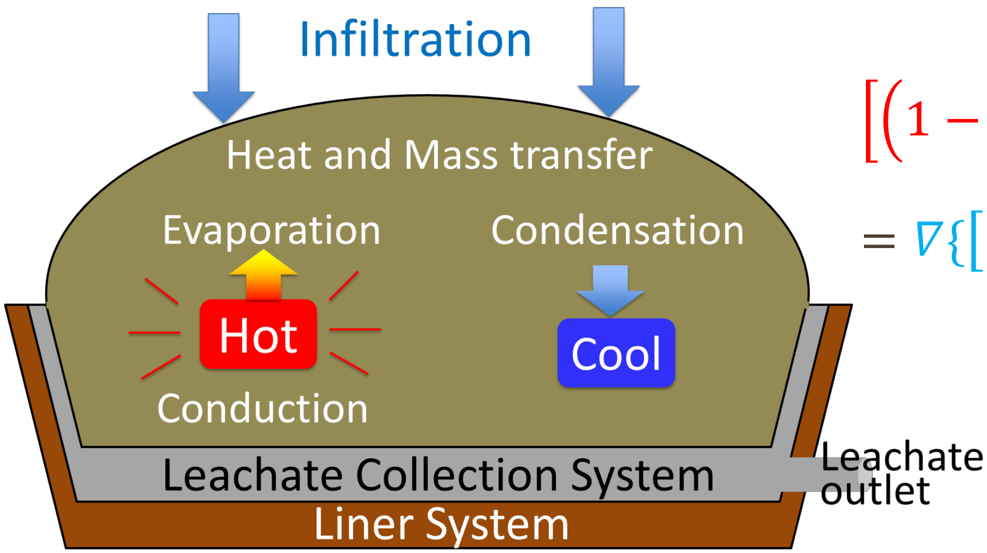
Advantages

1. Identified major sources of heat generation and heat loss
2. Simple and easy to code
3. Fast run time

Limitations

1. Uniform waste disposed at one time
2. No consideration of fill sequence or geometry
3. No heat and mass transfer impacts
4. No spatially resolved temperature information

The 3D Finite Element Model (3D-FEM)



Physical Processes

accumulation **convection**

$$\left[\left(1-\varepsilon\right)\rho_s C_{ps} + \varepsilon\rho_f C_{pf}\right]\frac{\partial T}{\partial t} + \left(\rho_f C_{pf} u_f\right)\nabla T$$

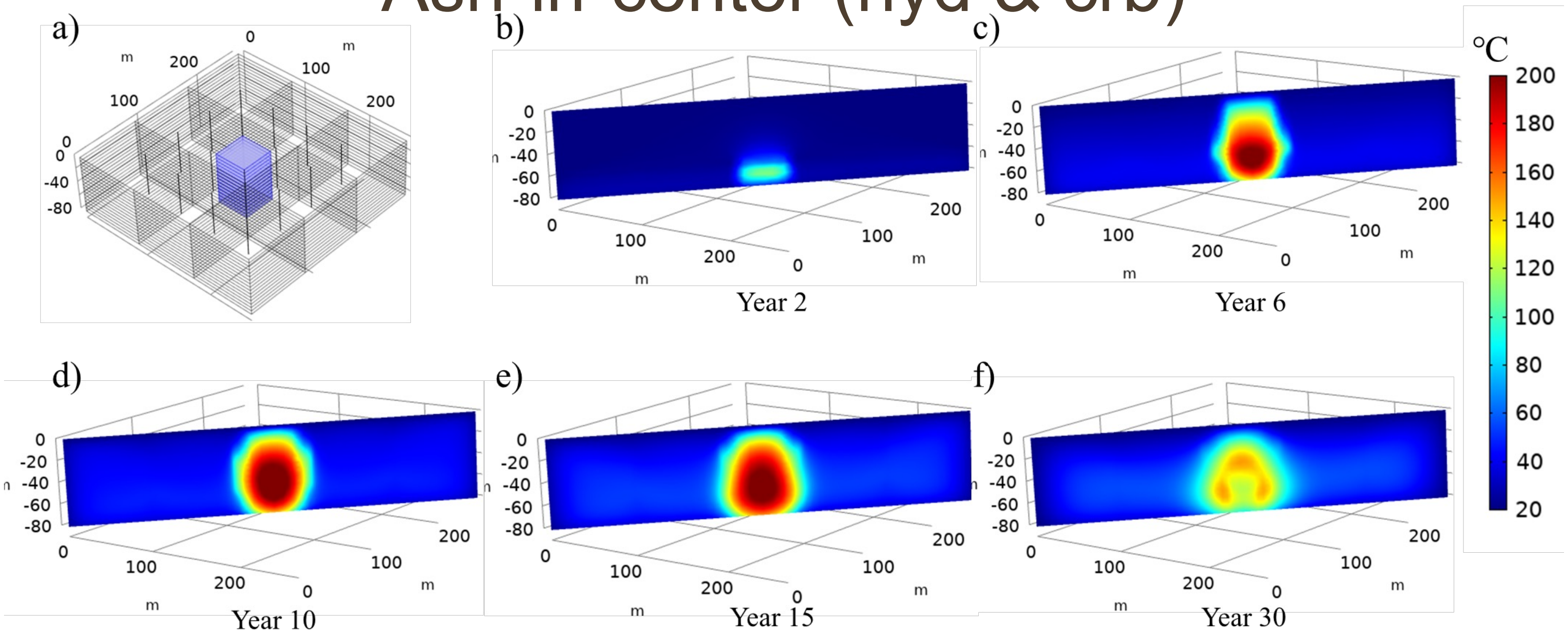
$$= \nabla\left\{\left[\left(1-\varepsilon\right)\kappa_s + \varepsilon\kappa_f\right]\nabla T\right\} + \sum_{\substack{i=bio,\\ chem,\\ condens.}} Q_i$$

conduction

sources

Mass balance

Ash-in-center (hyd & crb)



- Heat conduction is dominant due to large temp gradient
- Convective heat transfer (center to bottom) < conductive heat transfer (center to top)
- Uncertainty: enthalpy of ash hydration/carbonation, kinetics

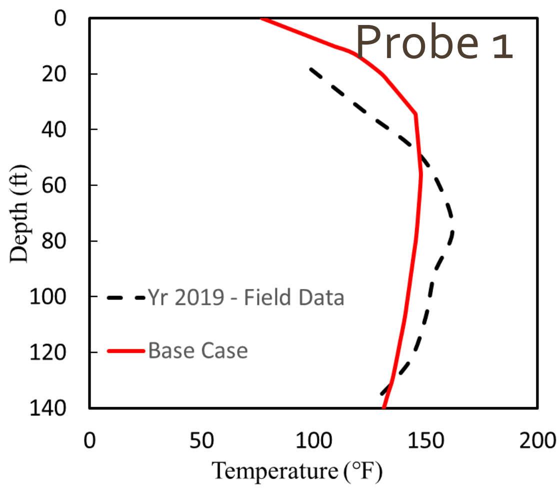
Cumulative Normalized Landfill Volume (CNLV)

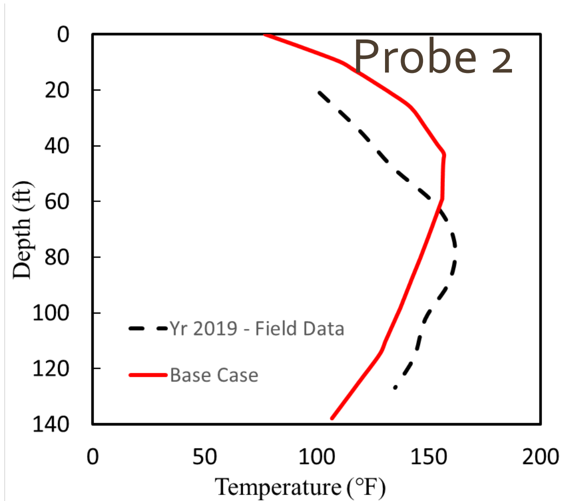
Case	CNLV > 65 °C	CNLV > 80 °C	Max T at waste bottom zone (°C)
MSW only	0	0	37
ash-in-center (segregated, hyd + crb)*	0.07	0.05	139
ash-in-corner (segregated, hyd + crb)	0.06	0.04	173
ash-in-center (segregated, crb ONLY)	0.03	0.02	85
10% ash (mixed with MSW, hyd + crb)	0.47	0	49
20% ash (mixed with MSW, hyd + crb)	0.81	0.63	65
1.7% Al (mixed with MSW)	0.59	0	54
3.4% Al (mixed with MSW)	0.86	0.71	86

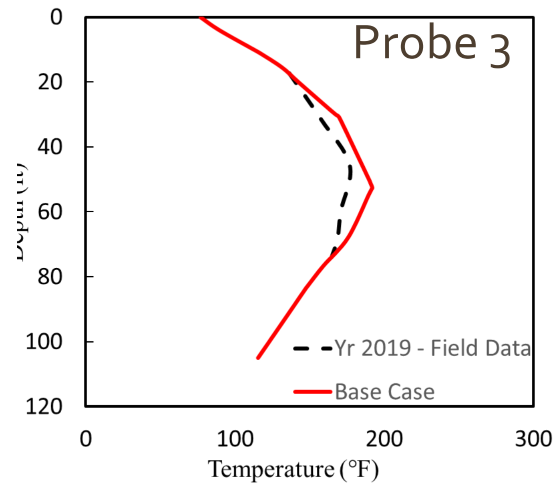
*hyd = hydration; crb = carbonation

- Corner scenario has a smaller but hotter elevated temperature region
- **Pre-hydrating ash is an effective approach to reduce the energy in the ash**
  - **Field test worked**
- **Segregation of reactive wastes has merit due to the decreasing CNLV**

Comparison to field data was successful



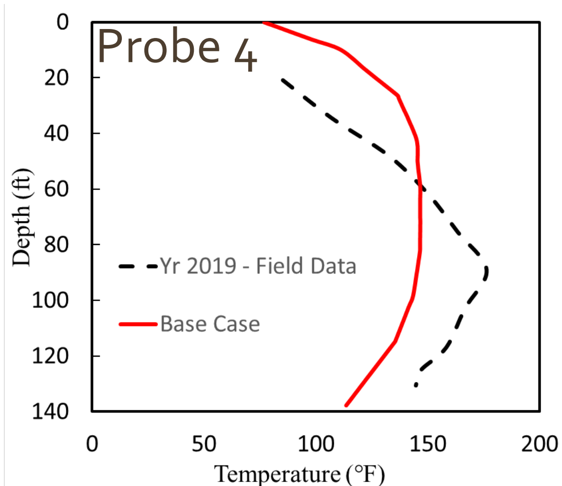


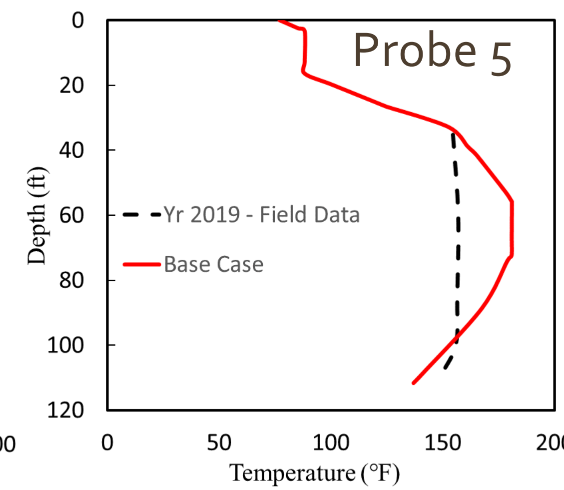


Initial T = 25 C

Top T = 25 C

Bottom T -
at 5 m soil = 15 C





Experimental Work to Parameterize Model

- Work by Castaldi did not show significant exothermic pyrolysis as initiator
- Method developed to measure heats of hydration and carbonation in
  - A calorimeter
    - Adding $KHCO_3$ enables capture heat of carbonation as well as hydration
      - No one was talking about the heat of carbonation before the research program started and it generates more heat than hydration
  - A reactor system (Monday morning) which taught us that there are are other reactions occurring that we had not considered (salt dissolution)
  - Aluminum corrosion

Aluminum Corrosion

- The rate and extent of aluminum corrosion increased with temperature and was not measurable at 60 °C. The absence of measurable corrosion at 60 °C suggests that Al corrosion does not contribute to conditions that would initiate an ETLF. If, however, a landfill was to reach 70 °C as a result of other waste inputs, then Al corrosion would exacerbate heat generation.
- The variability in behavior among the 3 leachates illustrates the difficulty in understanding how aluminum might behave in a specific landfill.
- In general, aluminum corrosion was greatest in foil followed by sheet and then cans.
- A landfill operator should not dispose of large amounts of foil or sheet in a concentrated area without planning for potential heat and H_2 generation.
- Alkaline conditions are known to accelerate Al corrosion. As such, the co-disposal of ash and concentrated aluminum should be avoided. Previous work on heat generation from ash that was supported by EREF also suggested that ash be segregated for disposal.

Process research on temperature impacts

Landfill A (LFA)

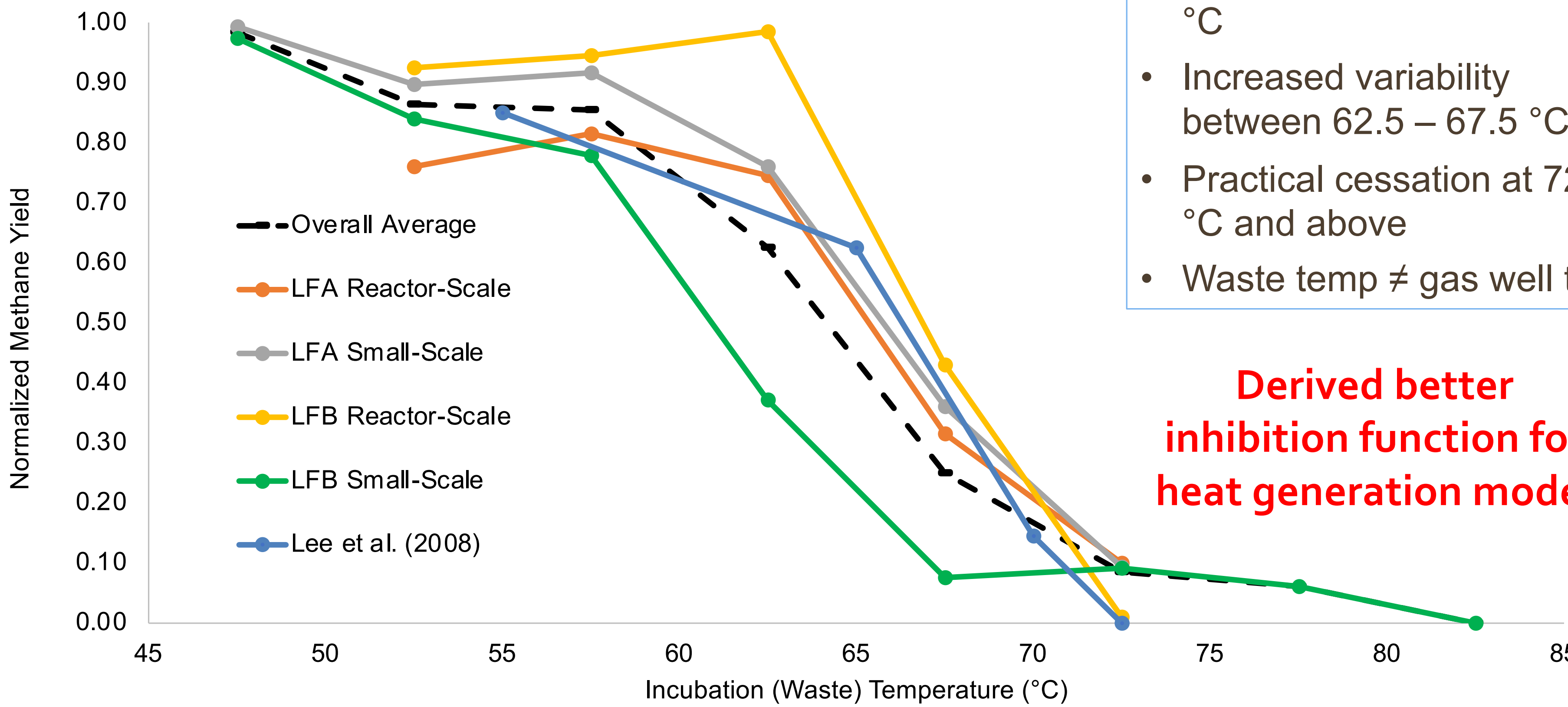
Depth (m)	Temp (°C)
6	55
9	52
12	58
15	63
18	67
21	64
21	70
24	75

Landfill B (LFB)

Depth (m)	Temp °(C)
9	52
9	60
12	61
12	67
15	70
15	71
18	74
21	79

Excavation Temperature = Recorded Waste Temperature On Site

Impact of Temperature on Methane Generation Summary



- Optimal between 47.5 - 57.5 °C
- Increased variability between 62.5 – 67.5 °C
- Practical cessation at 72.5 °C and above
- Waste temp ≠ gas well temp

Derived better inhibition function for heat generation model

Summary

- Excellent communication and idea exchange with landfill owners and operators
- Operators had field observations
- Research community developed theoretical understanding of what could be happening
- Academics published peer-reviewed articles which became important when there was litigation

Further Reading

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- Narode, A., Hao, Z., Pourghaz, M., Ducoste, J. J. and M. A. Barlaz, "Measurement and Temperature Prediction from Ash Disposed in Landfills Using a Quasi-Adiabatic Flow Reactor," submitted
- EREF Reports
  - Modeling Work
  - Experimental work on hydration, carbonation and corrosion (Submitted)

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