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New and Improved Landfill Gas Emissions Model

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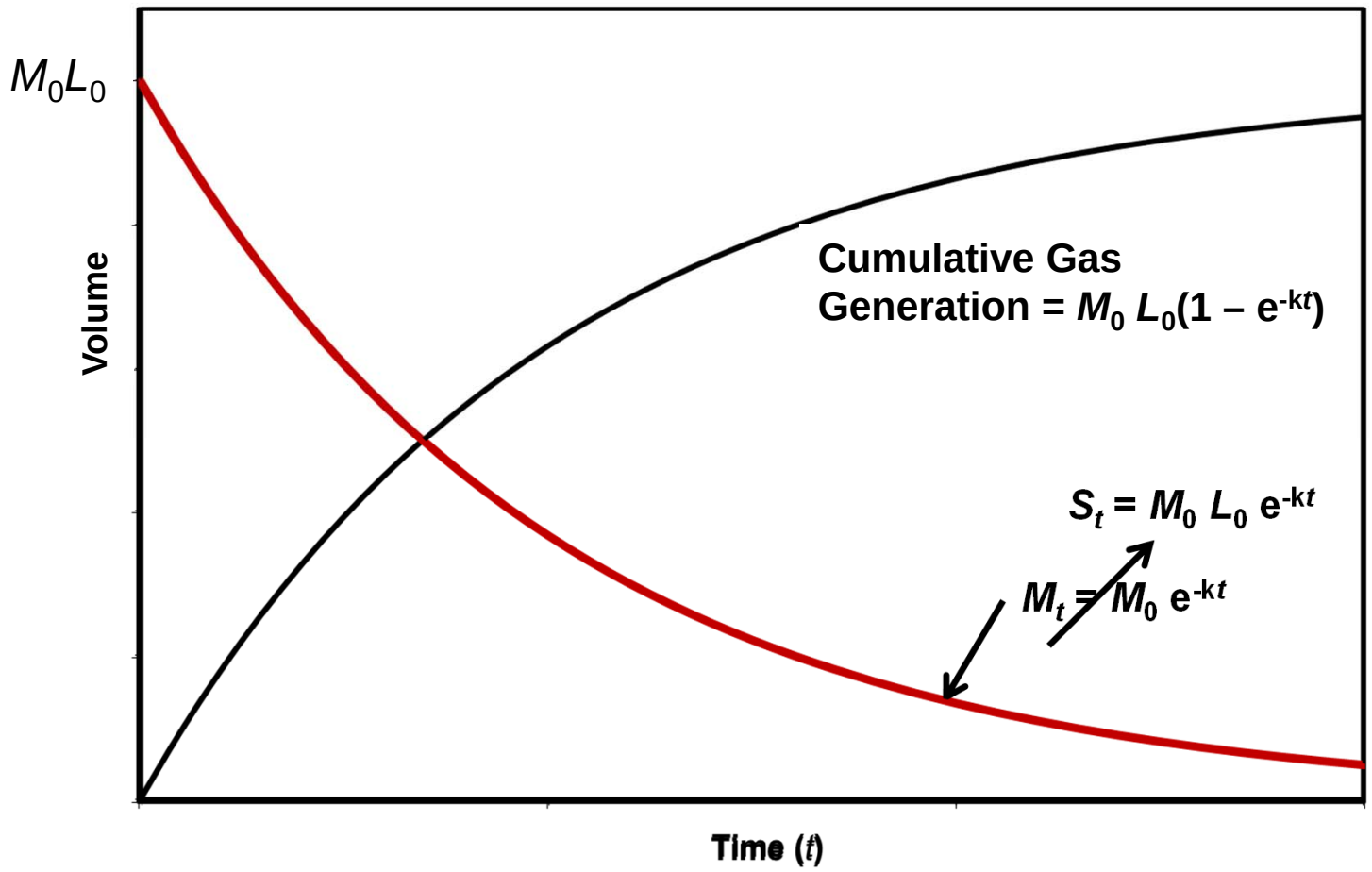
Outline

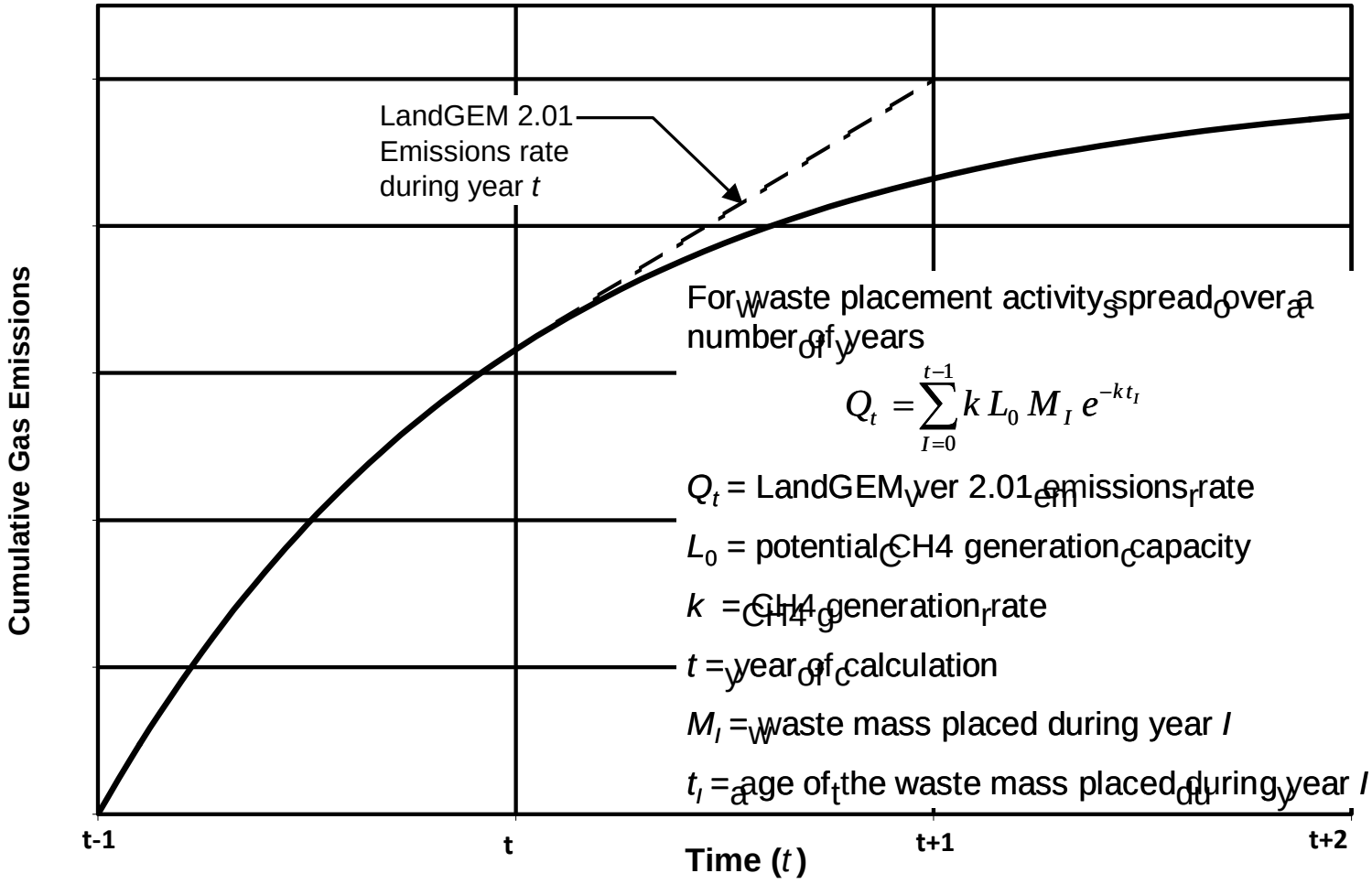
- Background
  - EPA LandGEM Models
  - LandGEM limitations
- New model
- Improvements
  - Varying parameters: k, L_0
  - Leachate re-circulation, climate change
  - Varying waste composition, L_0
  - …
- Validation
- Example model runs

Fundamentals

First order decay equation: $\frac{dM_t}{dt} = -k M_t$



Background: EPA's LandGEM 2.01



For waste placement activity spread over a number of years

$$Q_t = \sum_{I=0}^{t-1} k\, L_0\, M_I\, e^{-k t_I}$$

Q_t = LandGEM ver 2.01 emissions rate

L_0 = potential CH4 generation capacity

k = CH4 generation rate

t = year of calculation

M_I = waste mass placed during year I

t_I = age of the waste mass placed during year I

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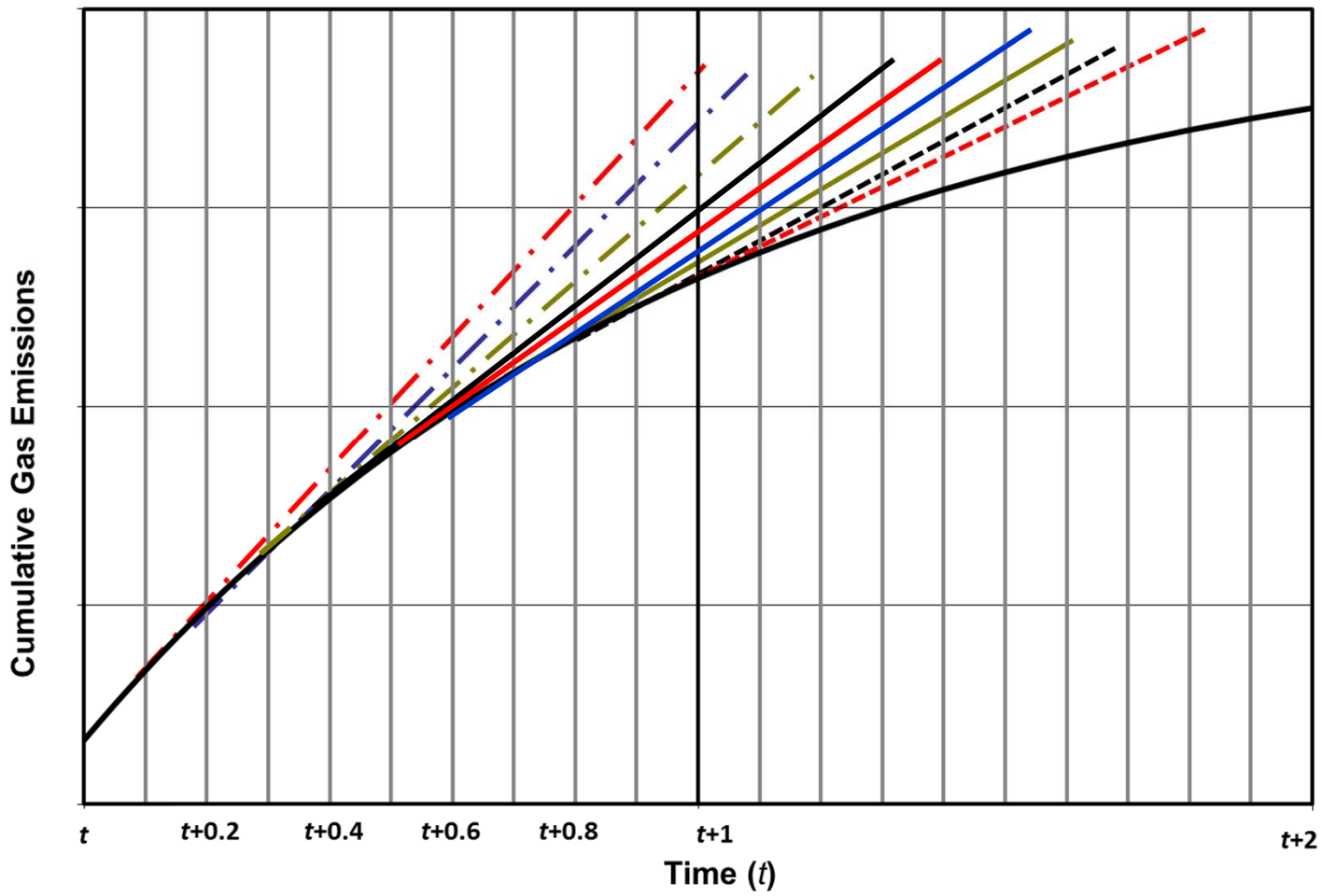
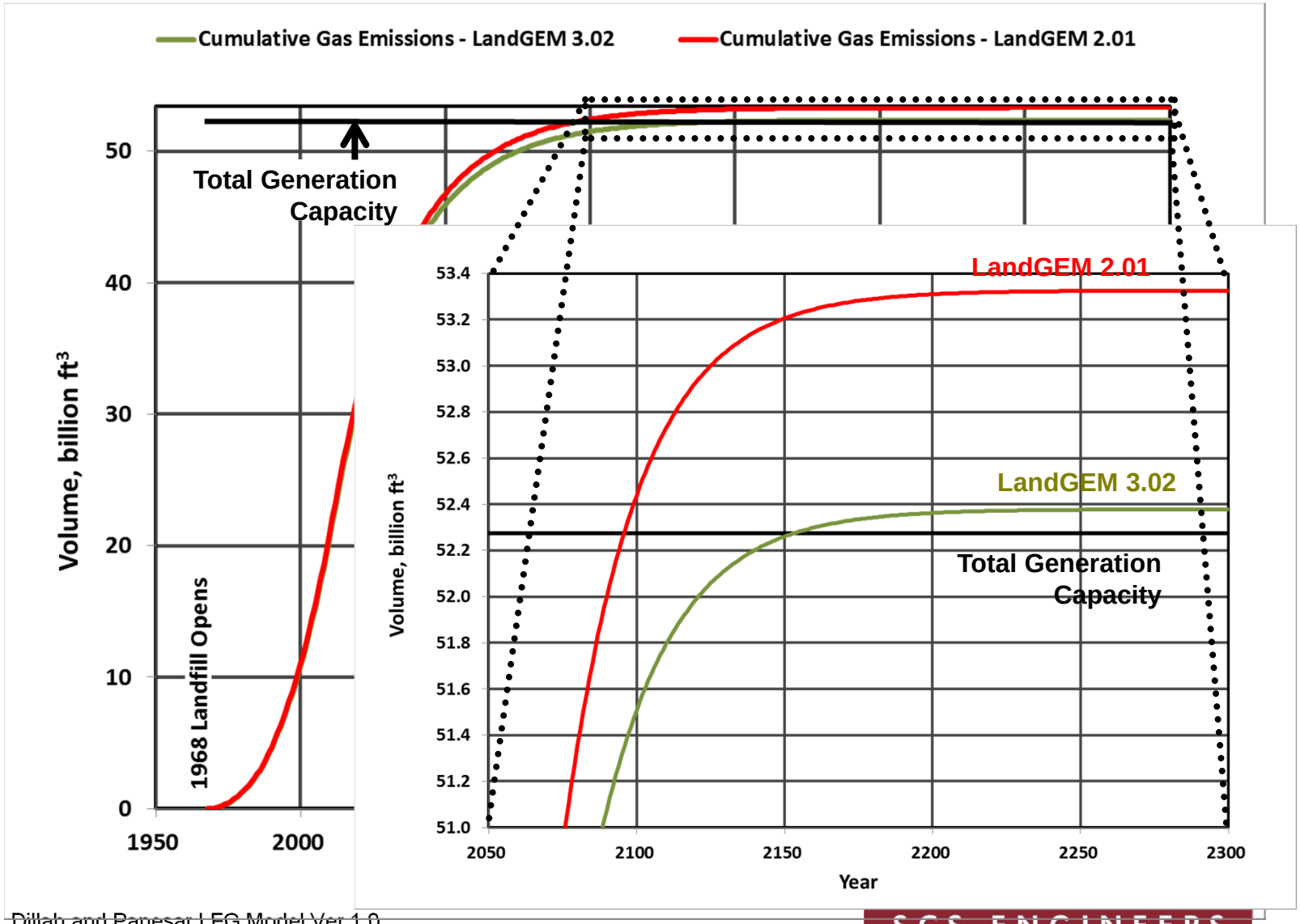
Background: EPA's LandGEM 3.02



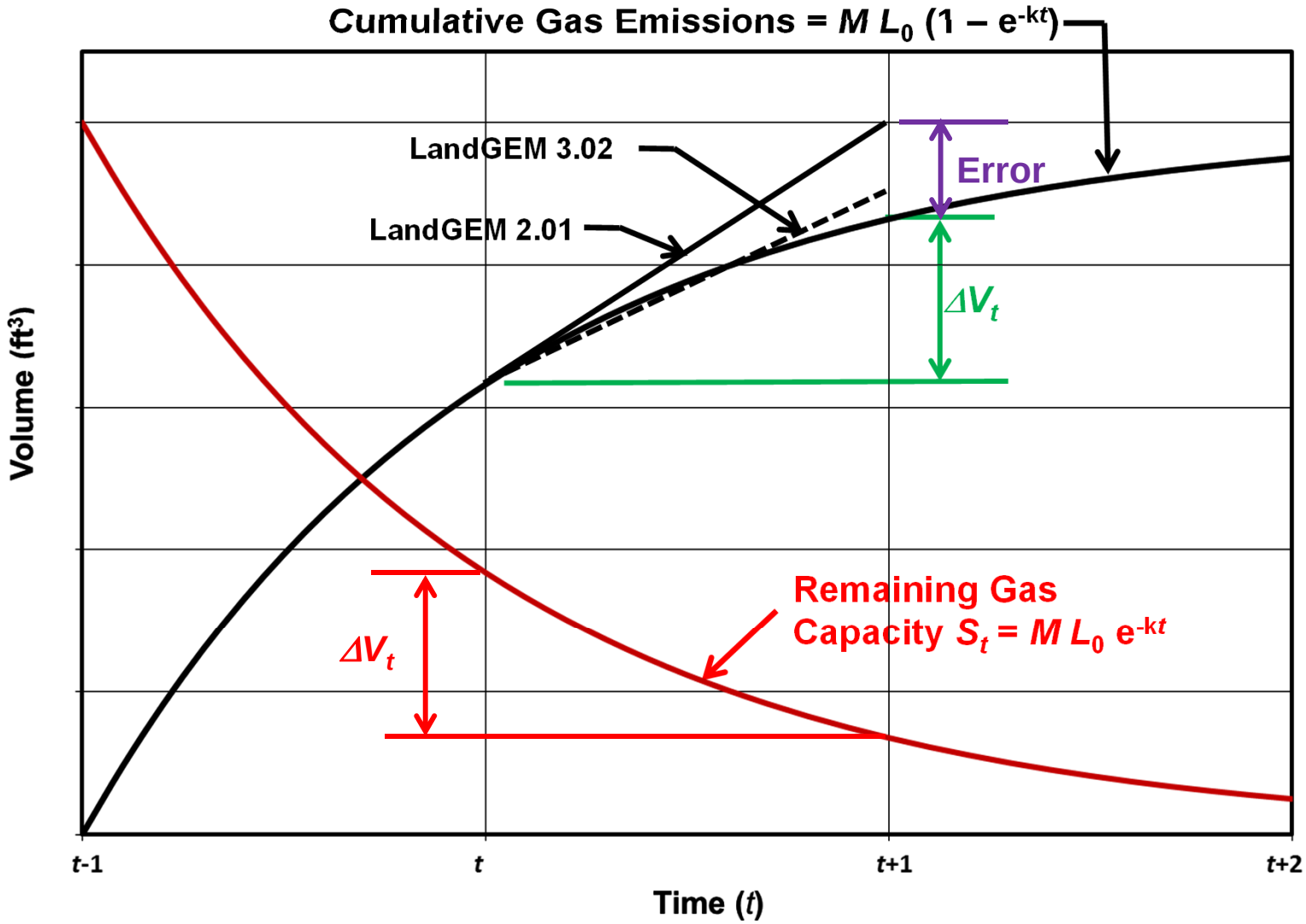
Background: LandGEM Strengths & Limitations

- Strengths of LandGEM
  - Simple in structure and easy to implement.
  - Only two model parameters; L_0 and k.
- LandGEM Limitations
  - L_0 and k cannot be changed during simulation.
  - Difficulties with handling:
    - Leachate re-circulation
    - Varying waste composition
    - Varying precipitation
  - Cumulative CH4 generation over infinite time period exceeds L_0.

Background: Cumulative CH4 Generation Vs. L_0



Model Accuracy



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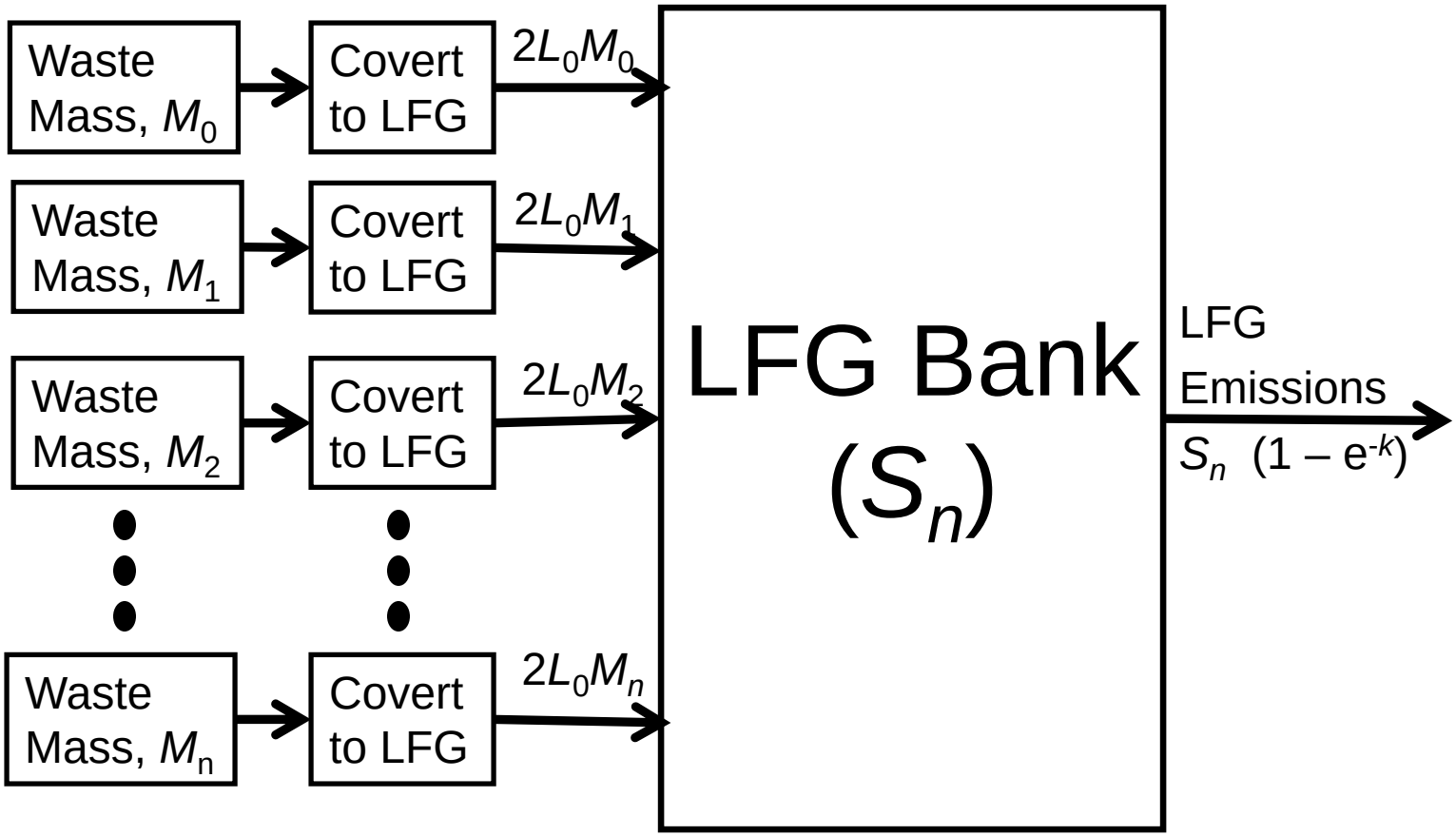
New Model


Waste Mass, M_0
Covert to LFG
$2L_0M_0$
Waste Mass, M_1
Covert to LFG
$2L_0M_1$
Waste Mass, M_2
Covert to LFG
$2L_0M_2$
Waste Mass, M_n
Covert to LFG
$2L_0M_n$
LFG Bank (S_n)
LFG Emissions
$S_n\ (1 - e^{-k})$

New Model

$$Q_n = S_n \left(1 - e^{-k_n \Delta t_n}\right) / \Delta t_n$$

$$S_{n+1} = S_n \, e^{-k_n \Delta t_n} + 2 \, L_{0,n} \, M_n \qquad \text{and} \quad S_0 = 0$$

where;

Q_n = LFG emissions during year n^{th} time period

S_n = Potential LFG generation capacity stored at the beginning of n^{th} time period

$L_{0,n}$ = Potential CH4 generation capacity of the waste placed during the n^{th} time period

k_n = CH4 generation rate during n^{th} time period

M_n = Amount of waste placed during n^{th} time period

Δt_n = n^{th} time period

Assumes LFG contains 50% methane

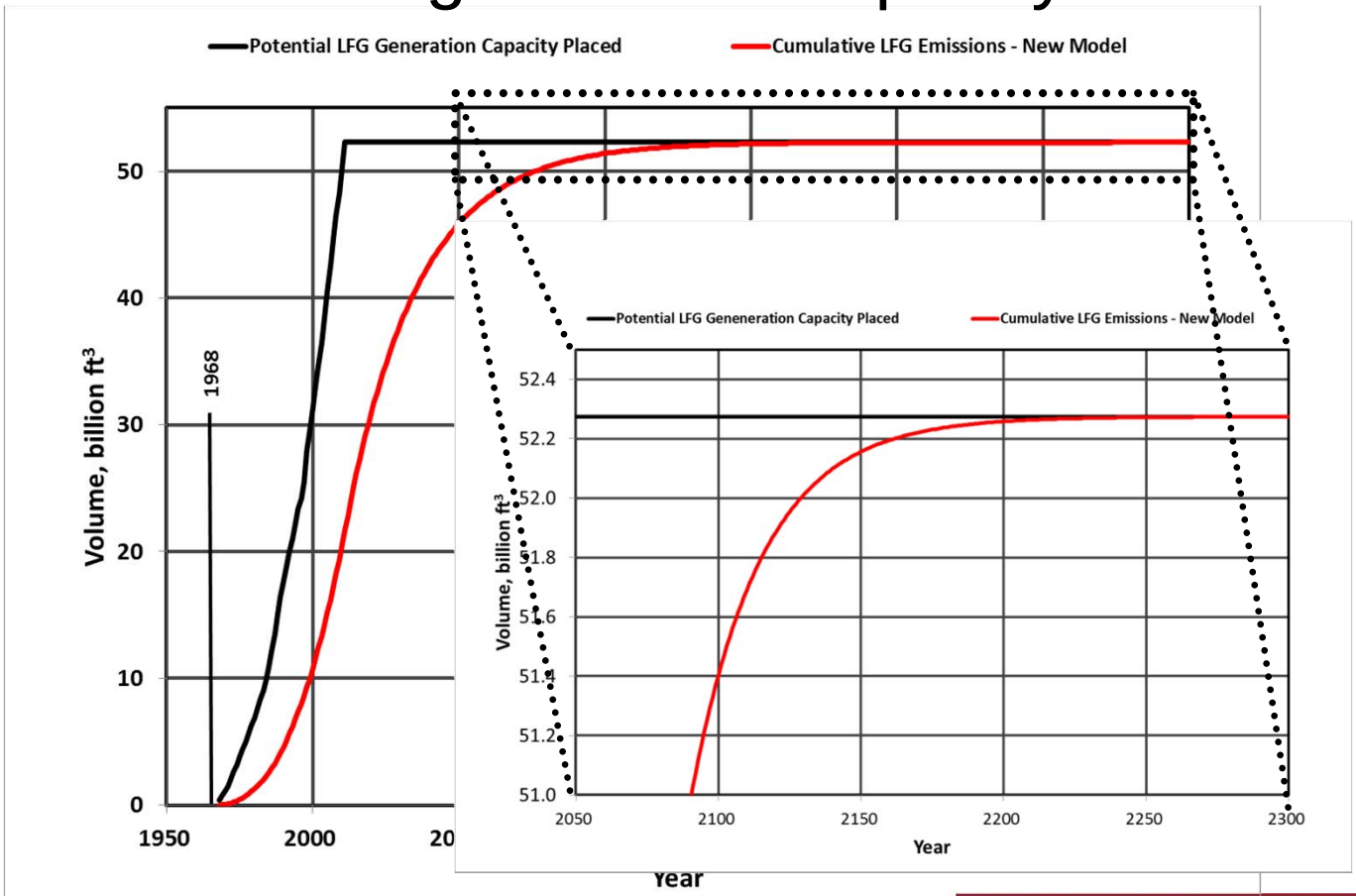
New Model - Improvements

- Further simplification to LandGEM
- Marriage between LandGEM and IPCC
- Exact mathematical representation of 1st order decay
- Model can handle varying parameters
  - L_0 (Varying Waste Composition)
  - k (Varying precipitation)
- Climate Change
- Bioreactor
- Leachate recirculation

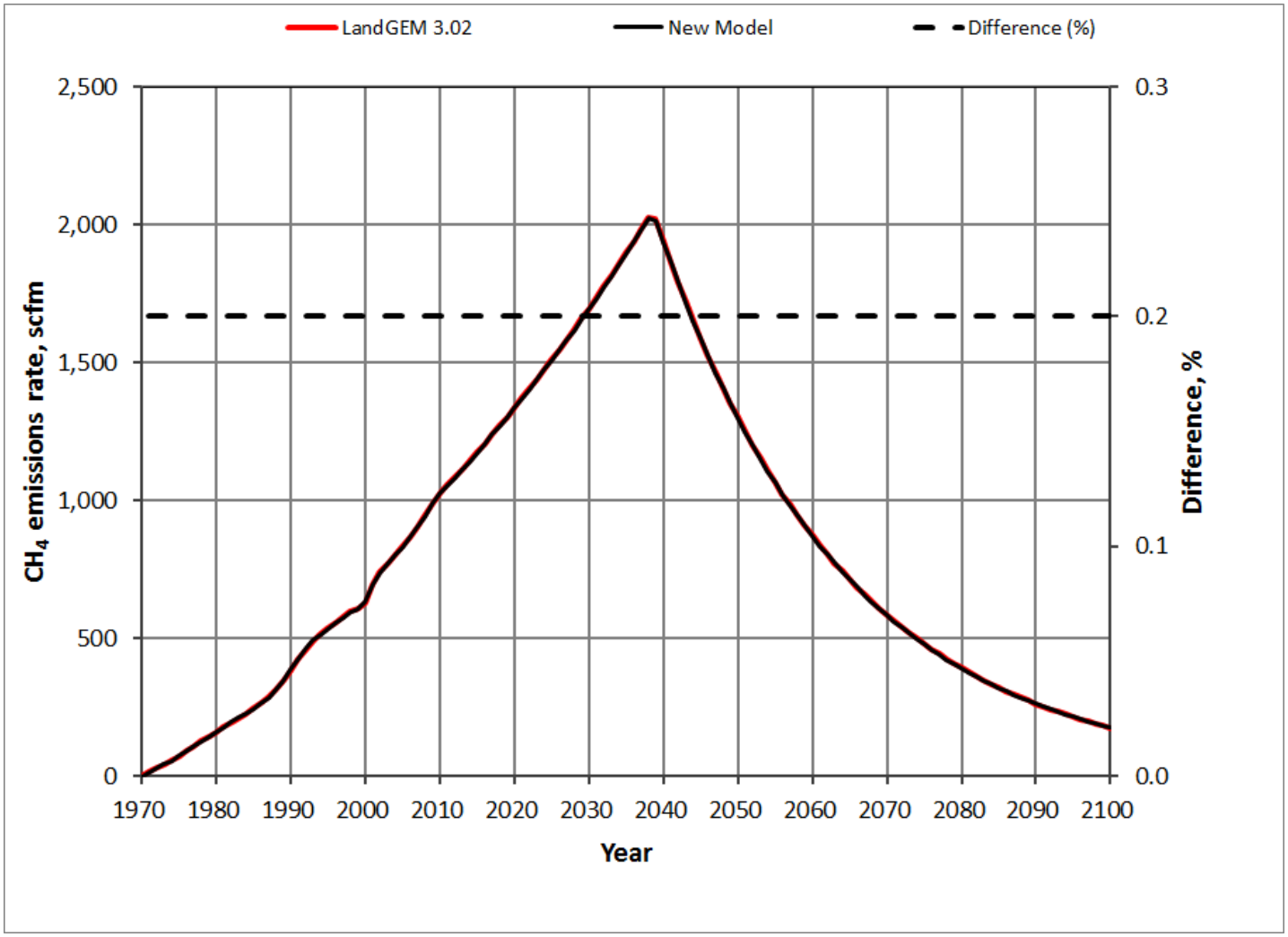
(IPCC = Intergovernmental Panel on Climate Change)

New Model - Improvements

- Cumulative emissions does not exceed potential LFG generation capacity



New Model Validation



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Example

- Virginia landfill
  - Varying k
  - Varying L_0

Example Landfill – LFG Emissions

- The worksheet

Landfill Gas Emissions Rates for Example Landfill							
Period		Waste disposed (ton)	L_0 (ft^3 CH4/ton)	k (per year)	LFG Bank, S_n at beginning of the period (ft^3 LFG)	Gas emissions rate (scfm)	
Start	End					LFG	CH4
1/1/1970	12/31/1970	59,999	3,204	0.04	0	0	0
1/1/1971	12/31/1971	60,043	3,204	0.04	384,473,592	29	14
1/1/1972	12/31/1972	59,966	3,204	0.04	754,153,711	56	28
1/1/1973	12/31/1973	59,966	3,204	0.04	1,108,686,254	83	41
1/1/1974	12/31/1974	83,886	3,204	0.04	1,449,359,442	108	54
1/1/1975	12/31/1975	86,201	3,204	0.04	1,929,918,136		
1/1/1976	12/31/1976	88,185	3,204	0.04	2,406,620,972		
1/1/1977	12/31/1977	91,382	3,204	0.04			
1/1/1978	12/31/1978	93,366	3,204	0.04		250	125
1/1/1979	12/31/1979	95,791	3,204	0.04	3,815,917,654	285	142
1/1/1980	12/31/1980	98,216	3,204	0.04	4,280,122,111	318	159

G7 = F7*(1-EXP(-E7 *(A8- A7)/366))/ ((A8-A7)*24*60)

F7 = F6*EXP(-E6*(A7-A6)/365)+2*C6*D6

Note: The constant 365 or 366 is number of days in a non-leap or leap year.

Example Landfill – LFG Emissions

- Varying L_0

Landfill Gas Emissions Rates for Example Landfill							
Period		Waste disposed (ton)	L_0 (ft^3 CH4/ton)	k (per year)	LFG Bank, S_n at beginning of the period (ft^3 LFG)	Gas emissions rate (scfm)	
Start	End					LFG	CH4
1/1/1970	12/31/1970	59,999	3,204	0.04	0	0	0
1/1/1971	12/31/1971	60,043	3,204	0.04	384,473,592	29	14
1/1/1972	12/31/1972	59,966	3,204	0.04	754,153,711	56	28
1/1/1973	12/31/1973	59,966	3,204	0.04	1,108,686,254	83	41
1/1/1974	12/31/1974	83,886	3,204	0.04	1,449,359,442	108	54
1/1/1995	12/31/1995	173,063	3,204	0.04	14,254,563,471	1,063	532
1/1/1996	12/31/1996	174,165	3,204	0.04	14,804,621,747	1,101	551
1/1/1997	12/31/1997	185,188	2,403	0.04	15,337,056,271	1,144	572
1/1/1998	12/31/1998	134,482	2,403	0.04	15,624,080,440	1,166	583
1/1/1999	12/31/1999	197,314	2,403	0.04	15,656,126,974	1,168	584
1/1/2000	12/31/2000	382,502	2,403	0.04	15,990,532,539	1,190	595
1/1/2001	12/31/2001	297,624	3,204	0.04	17,198,472,421	1,283	641
1/1/2002	12/31/2002	241,406	3,204	0.04	18,429,474,501	1,375	687

Example Landfill – LFG Emissions

- Varying *k*

Landfill Gas Emissions Rates for Example Landfill							
Period		Waste disposed (ton)	L_0 (ft^3 CH4/ton)	*k* (per year)	LFG Bank, S_n at beginning of the period (ft^3 LFG)	Gas emissions rate (scfm)	
Start	End					LFG	CH4
1/1/1970	12/31/1970	59,999	3,204	0.04	0	0	0
1/1/1971	12/31/1971	60,043	3,204	0.04	384,473,592	29	14
1/1/1972	12/31/1972	59,966	3,204	0.04	754,153,711	56	28
1/1/1973	12/31/1973	59,966	3,204	0.04	1,108,686,254	83	41
1/1/1974	12/31/1974	83,886	3,204	0.04	1,449,359,442	108	54
1/1/2005	12/31/2005	283,181	3,204	0.04	20,968,016,606	1,564	782
1/1/2006	12/31/2006	299,370	3,204	0.04	21,958,265,120	1,638	819
1/1/2007	12/31/2007	311,522	3,204	0.06	23,013,320,286	2,550	1,275
1/1/2008	12/31/2008	340,751	3,204	0.06	23,669,361,822	2,615	1,308
1/1/2009	12/31/2009	314,348	3,204	0.06	24,467,170,572	2,711	1,355
1/1/2010	12/31/2010	292,029	3,204	0.06	25,052,868,000	2,776	1,388
1/1/2011	12/31/2011	280,374	3,204	0.06	25,461,346,248	2,821	1,410
1/1/2012	12/31/2012	308,590	3,204	0.04	25,775,229,466	1,918	959
1/1/2013	12/31/2013	311,274	3,204	0.04	26,736,585,726	1,994	997

Summary

- Further simplification to LandGEM
- Exact mathematical representation of 1st order decay
- New model handles:
  - *Varying k*
  - *Varying* L_0,
  - Or
    - leachate re-circulation; bioreactor
    - varying precipitation; climate change
    - varying waste composition; waste diversion

Questions?

Thank You
&
Please Contact us with Questions

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