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Landfill Process Modeling

Slides available at
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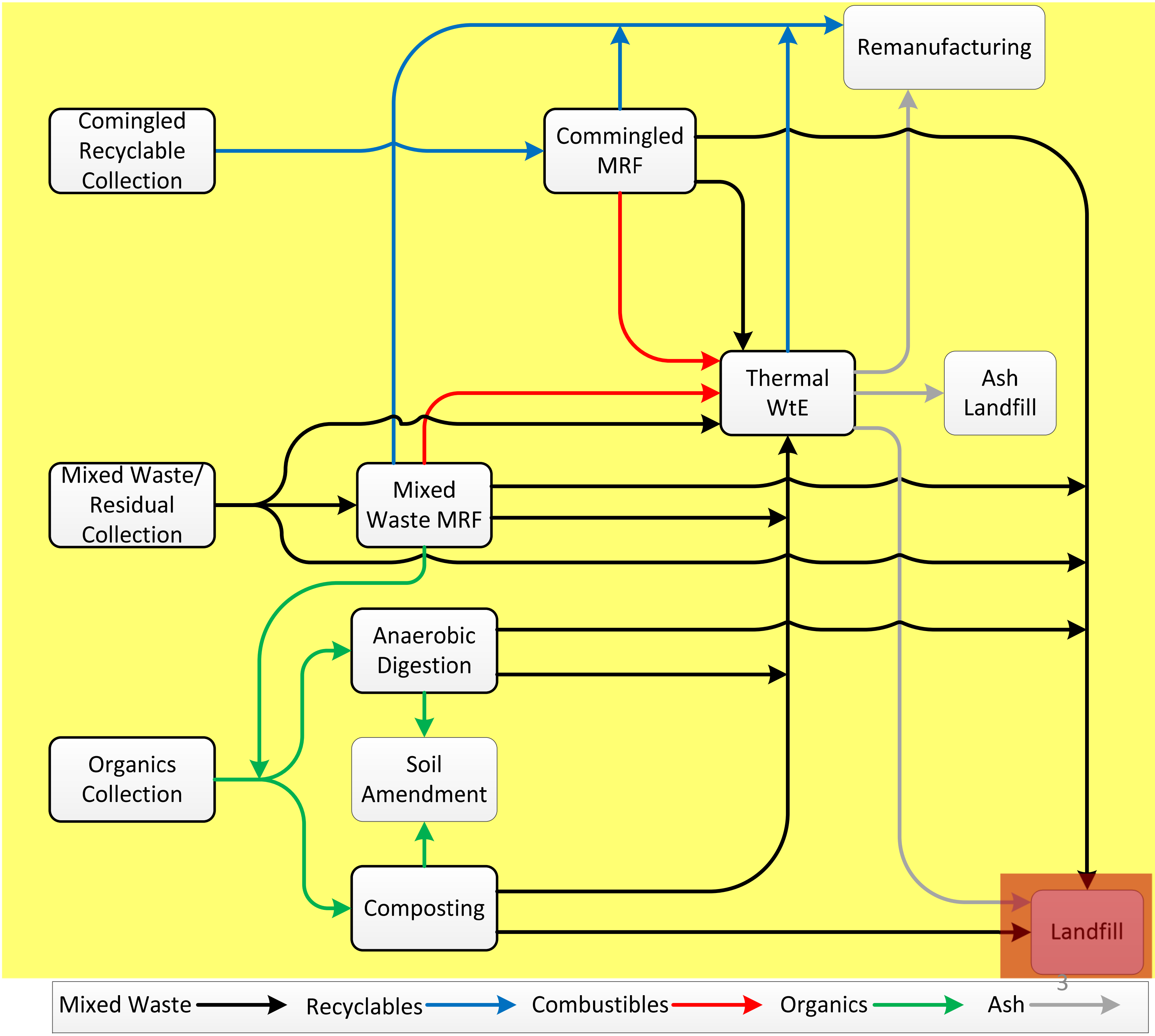
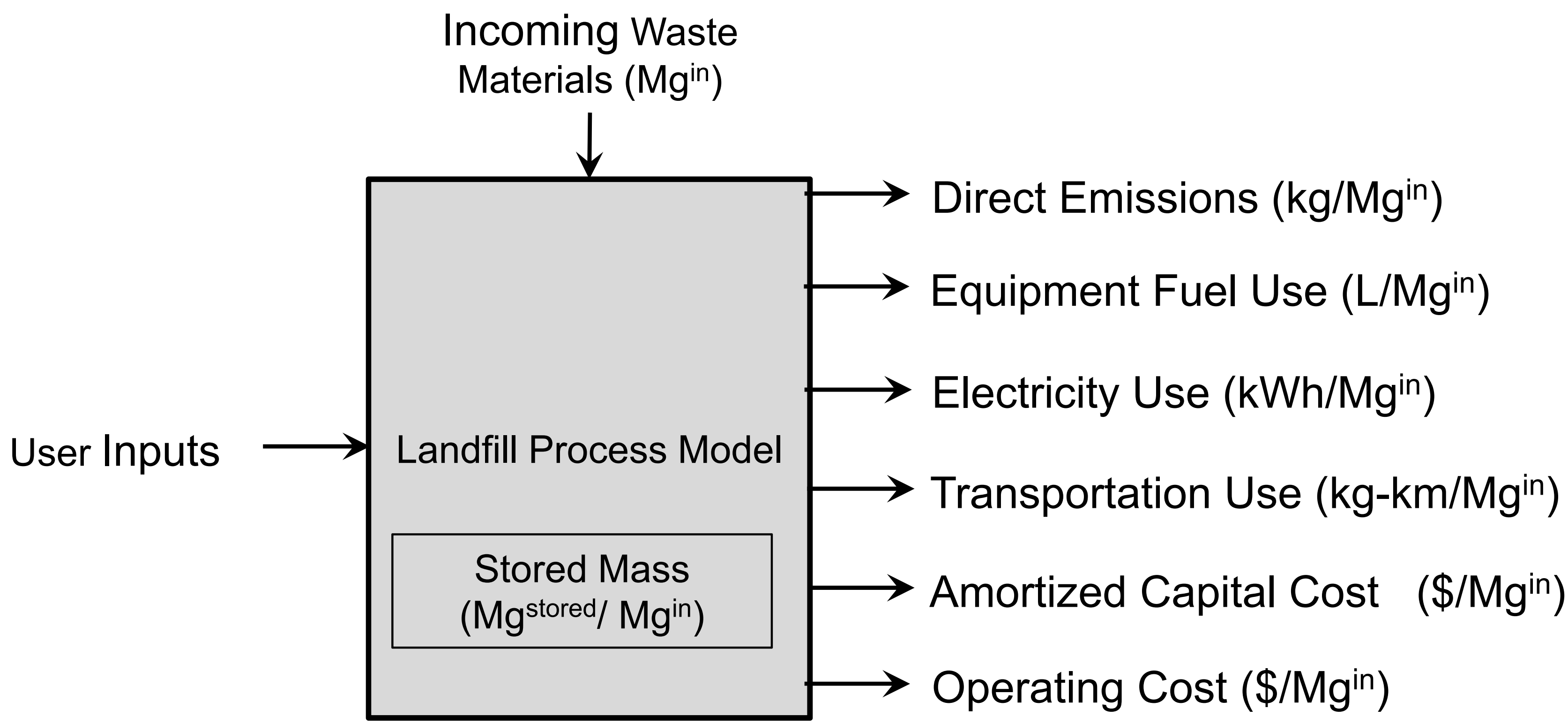
Outline

- Introduction
  - Functional Unit
- Carbon Flows
- Key Sub-Processes
- Modeling an average landfill
  - Consider multiple gas management scenarios

Solid Waste Systems



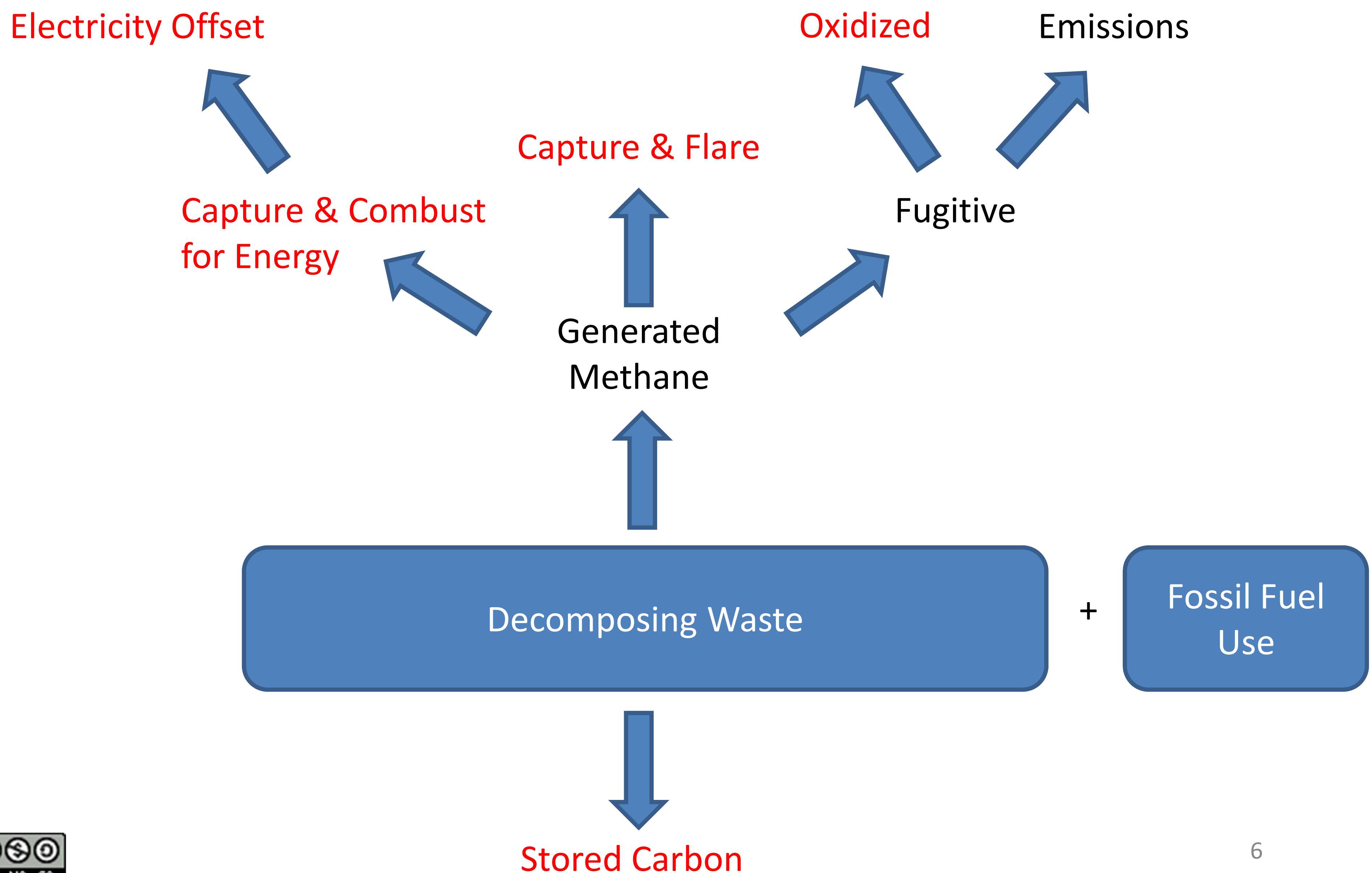
The Landfill Process Model



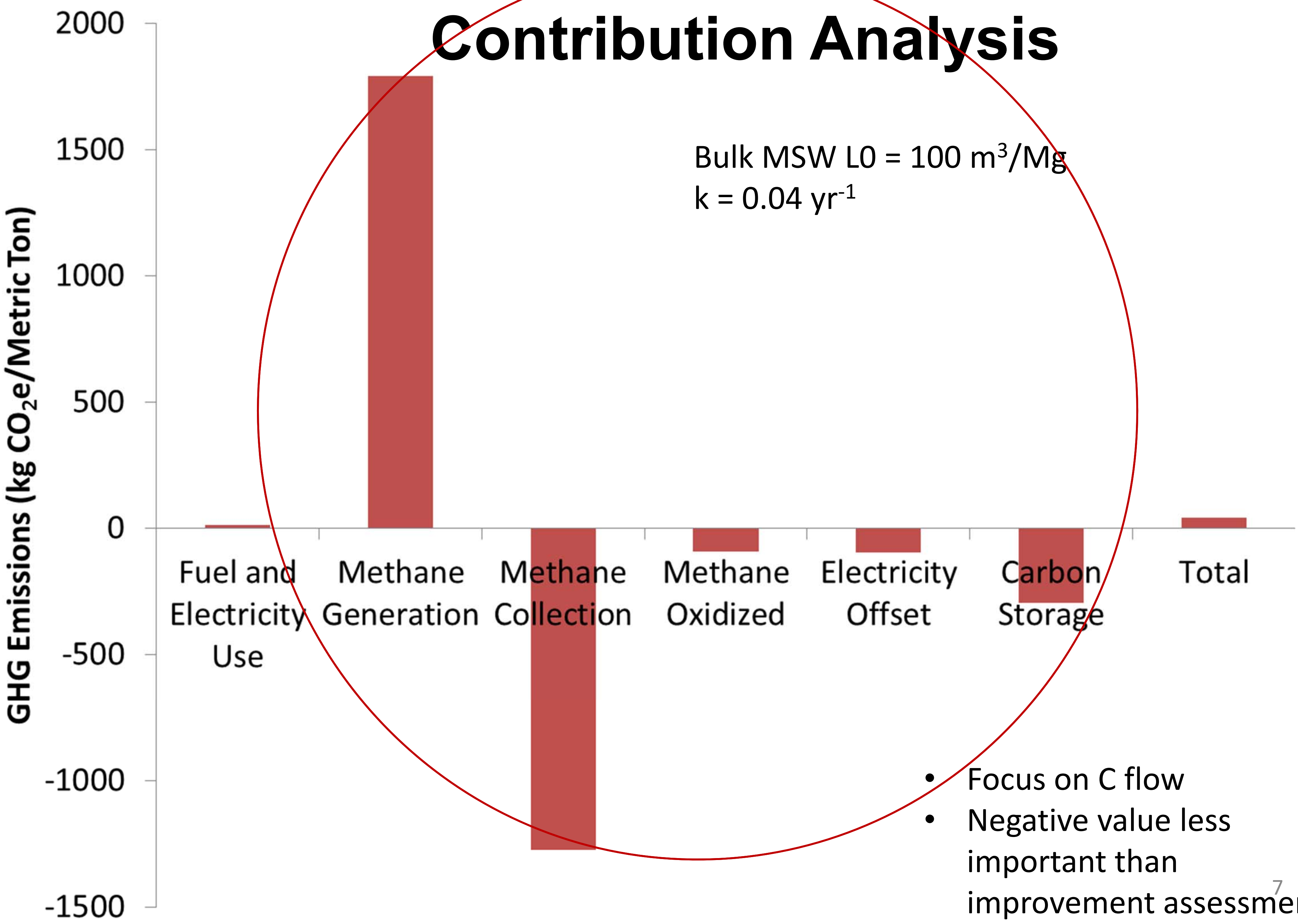
Functional Unit: Landfills or Waste in Landfills

- Appropriately defining the functional unit is essential for landfill life-cycle modeling
- There is confusion in functional units:
  - A representative unit volume in a landfill
  - The behavior over time of a mass of waste disposed in a landfill
- Modeling a landfill requires modeling waste disposed over years in different cells with phased collection and cover systems.
- Modeling a ton of waste in a landfill requires developing temporally averaged emissions from the waste placed at different times in the landfill
- SWOLF models a ton of waste disposed in a landfill which is appropriate for comparison of waste management alternatives

Landfill carbon flows

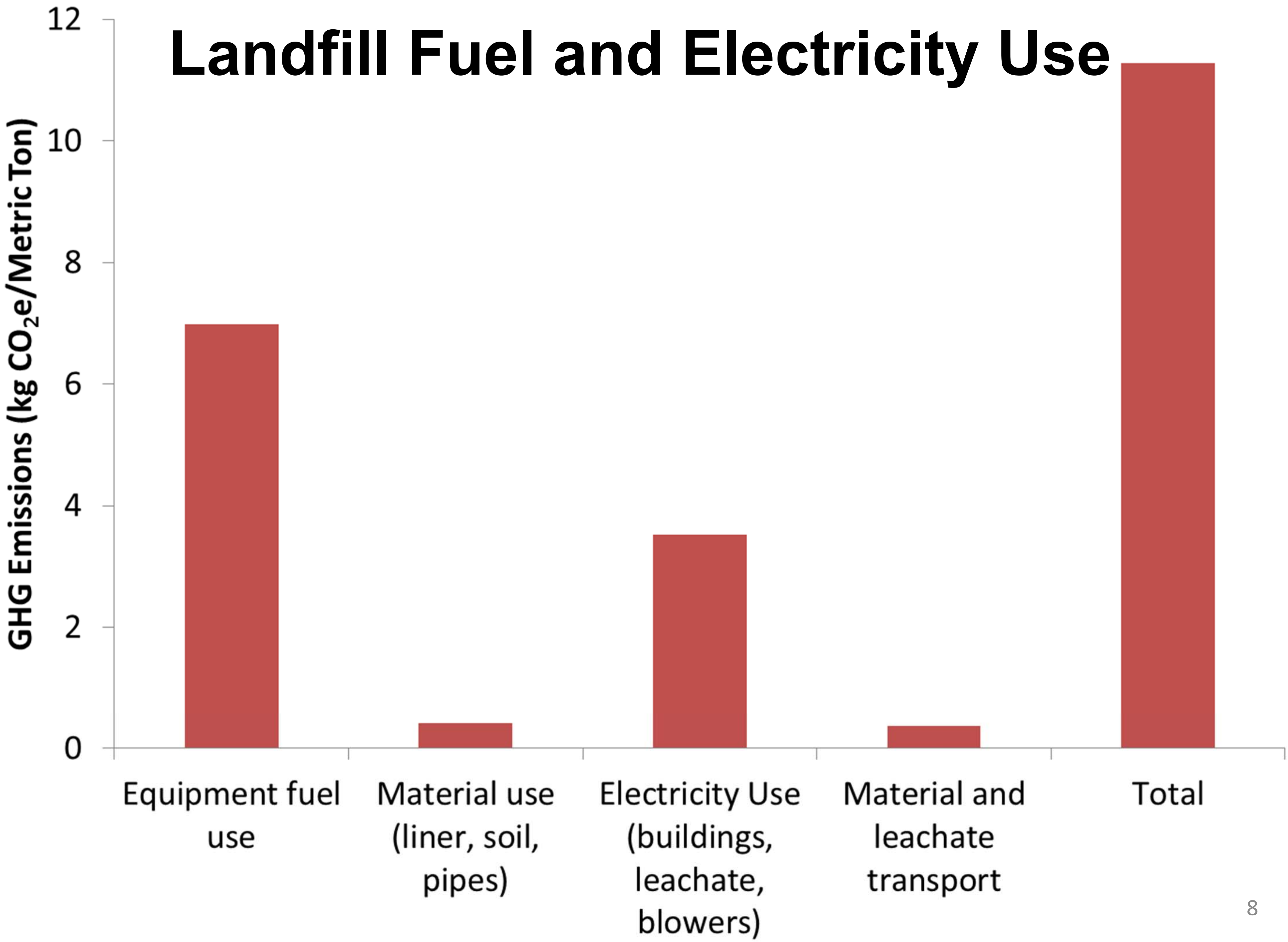


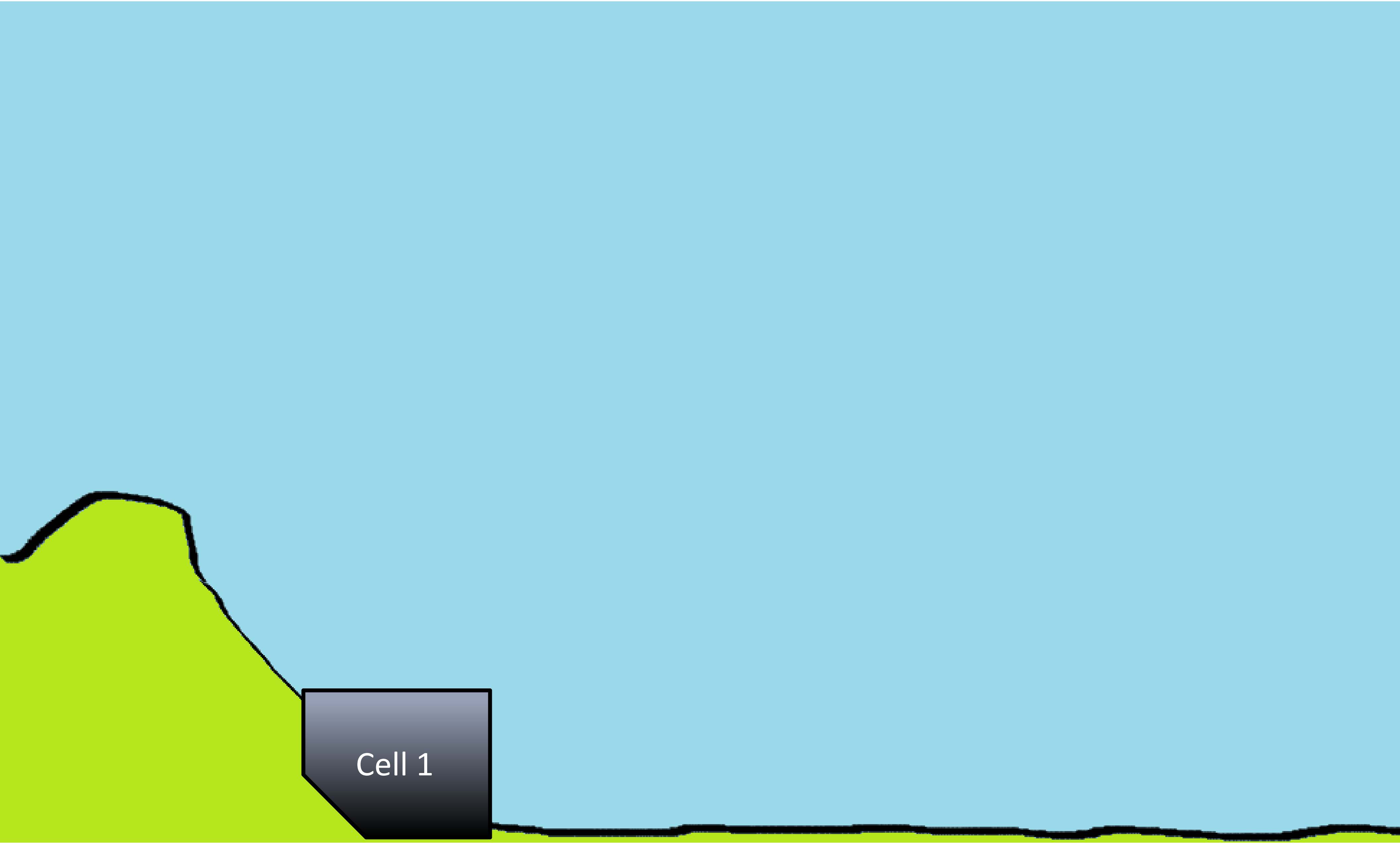
Contribution Analysis



- Focus on C flow
- Negative value less important than improvement assessment

Landfill Fuel and Electricity Use

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Cell 1
Cell 2
Cell 3

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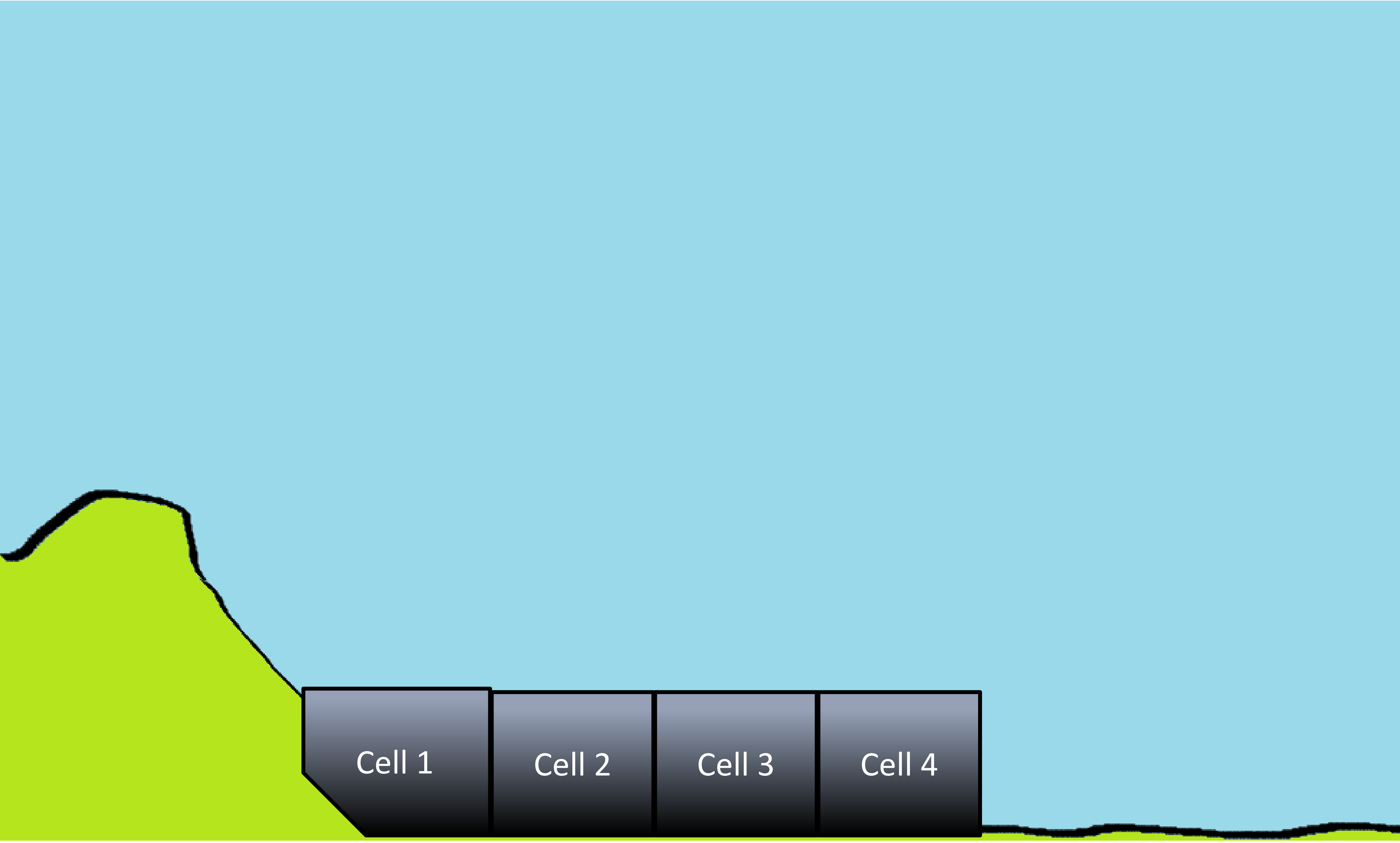


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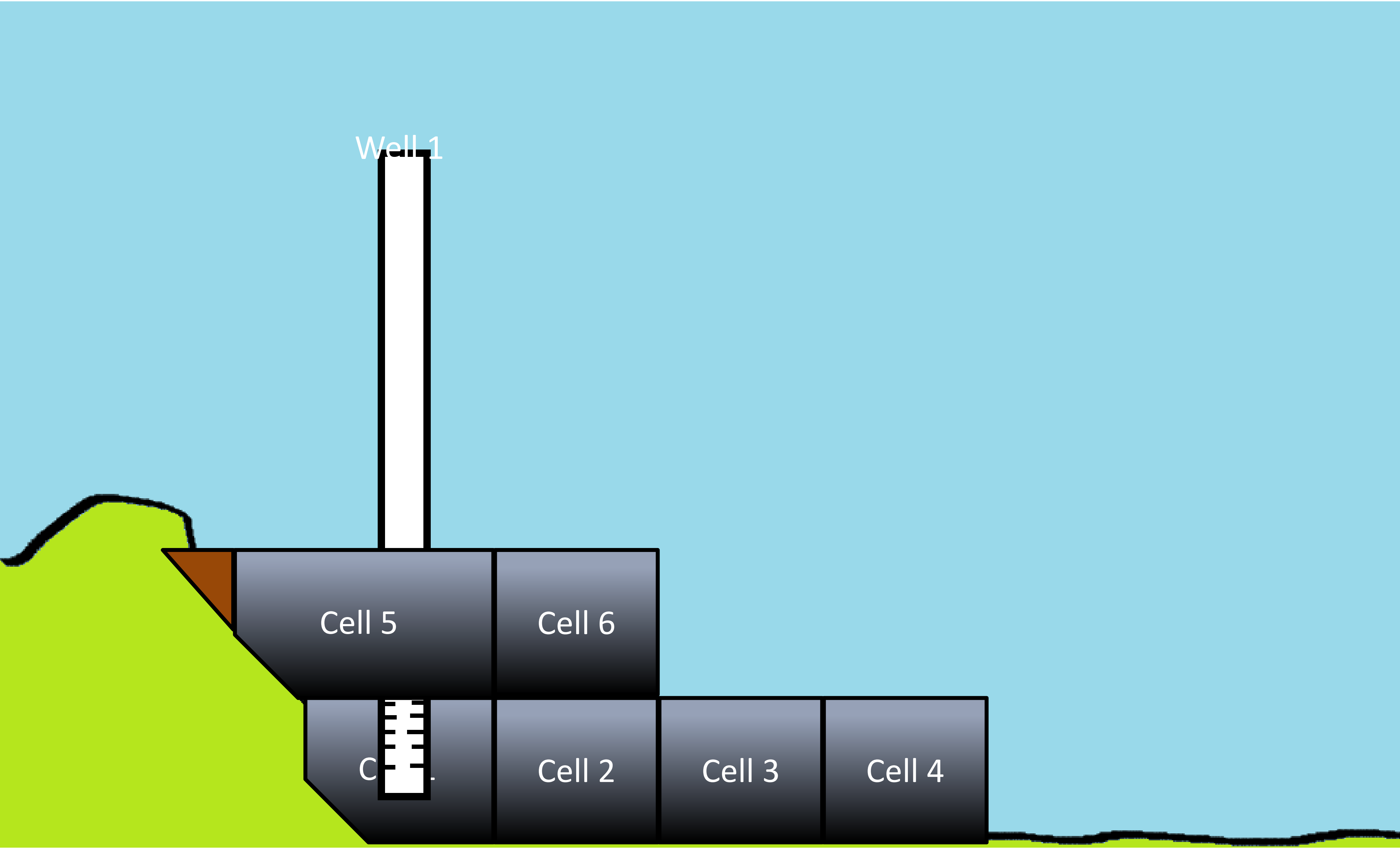
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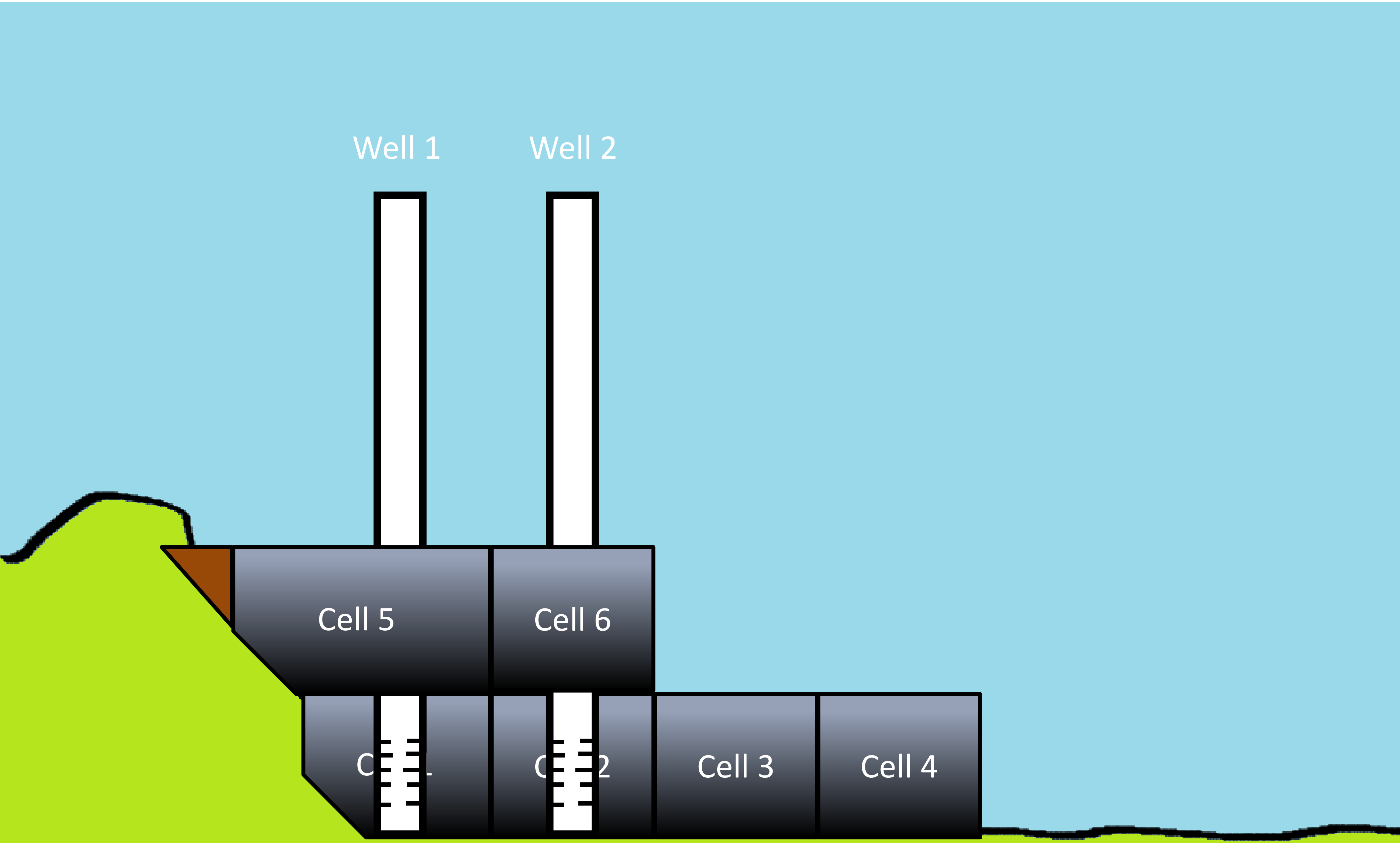
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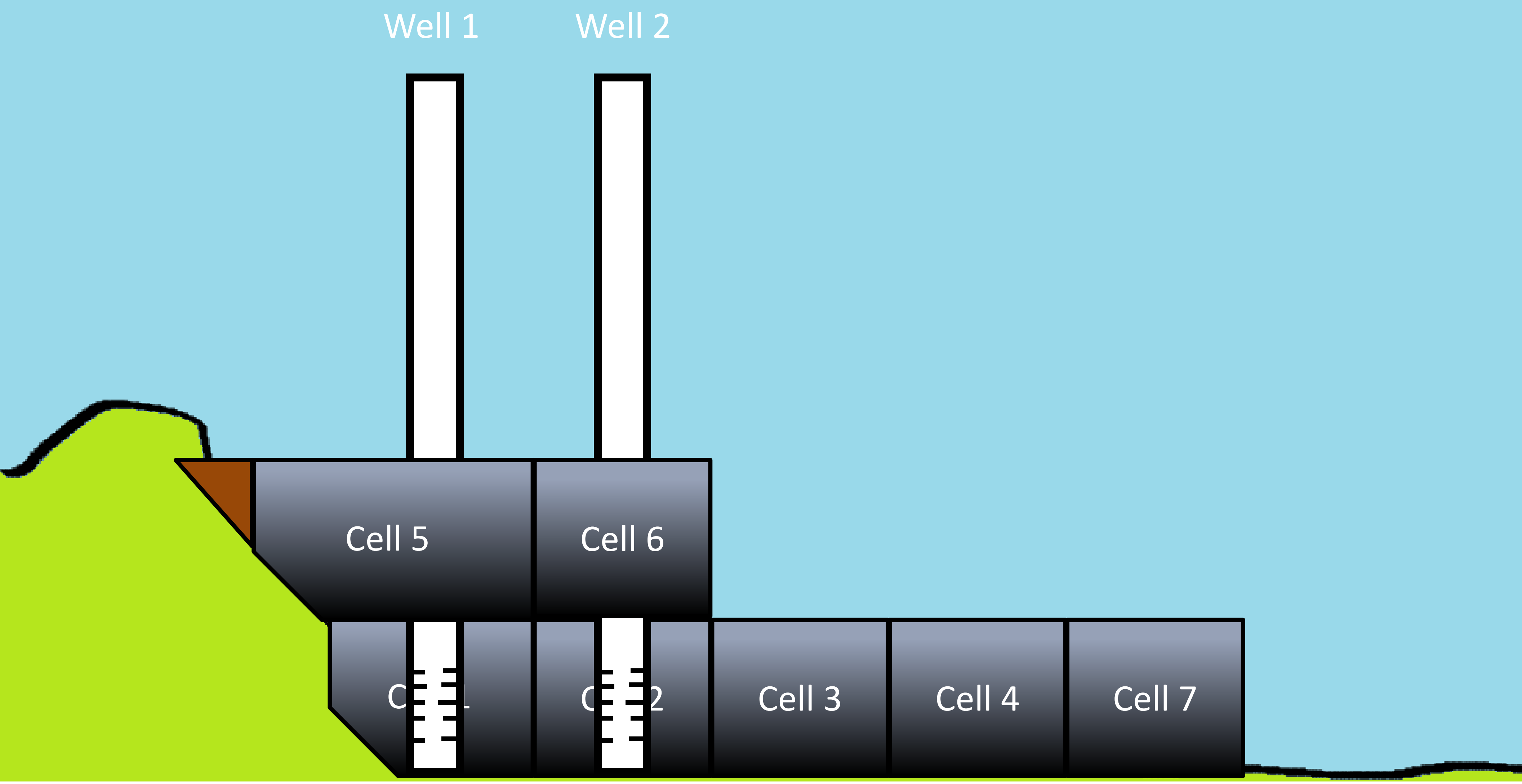
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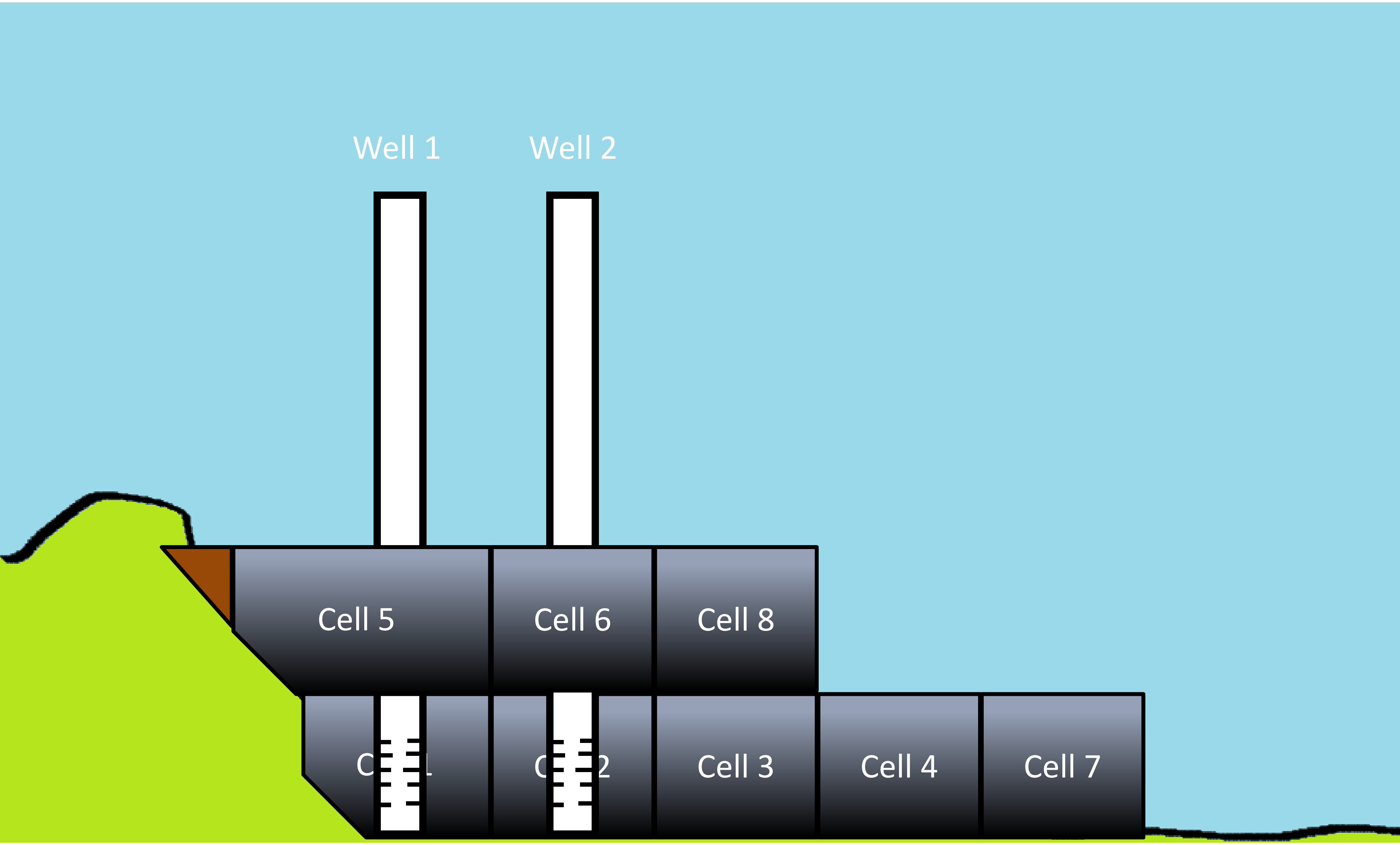
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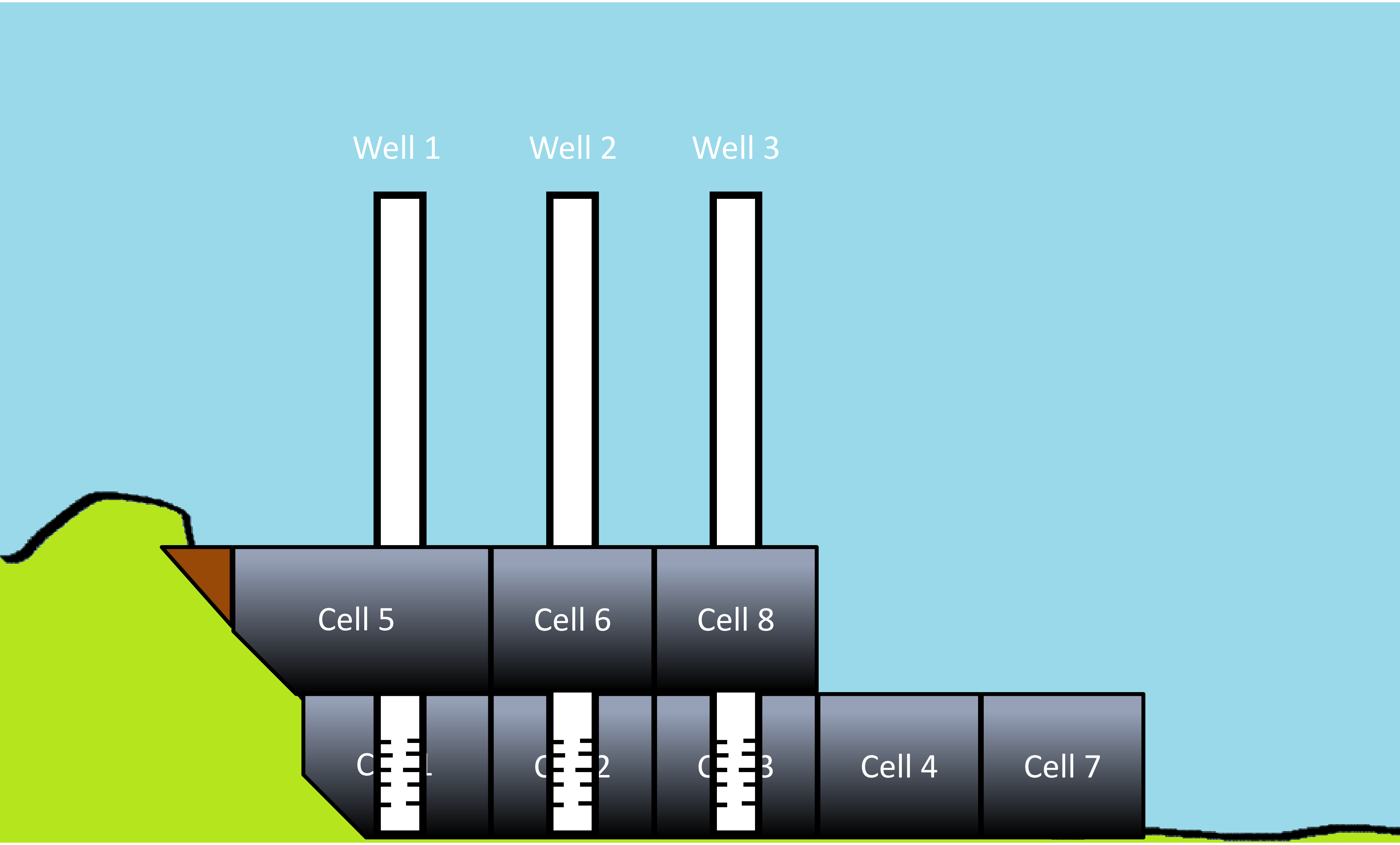
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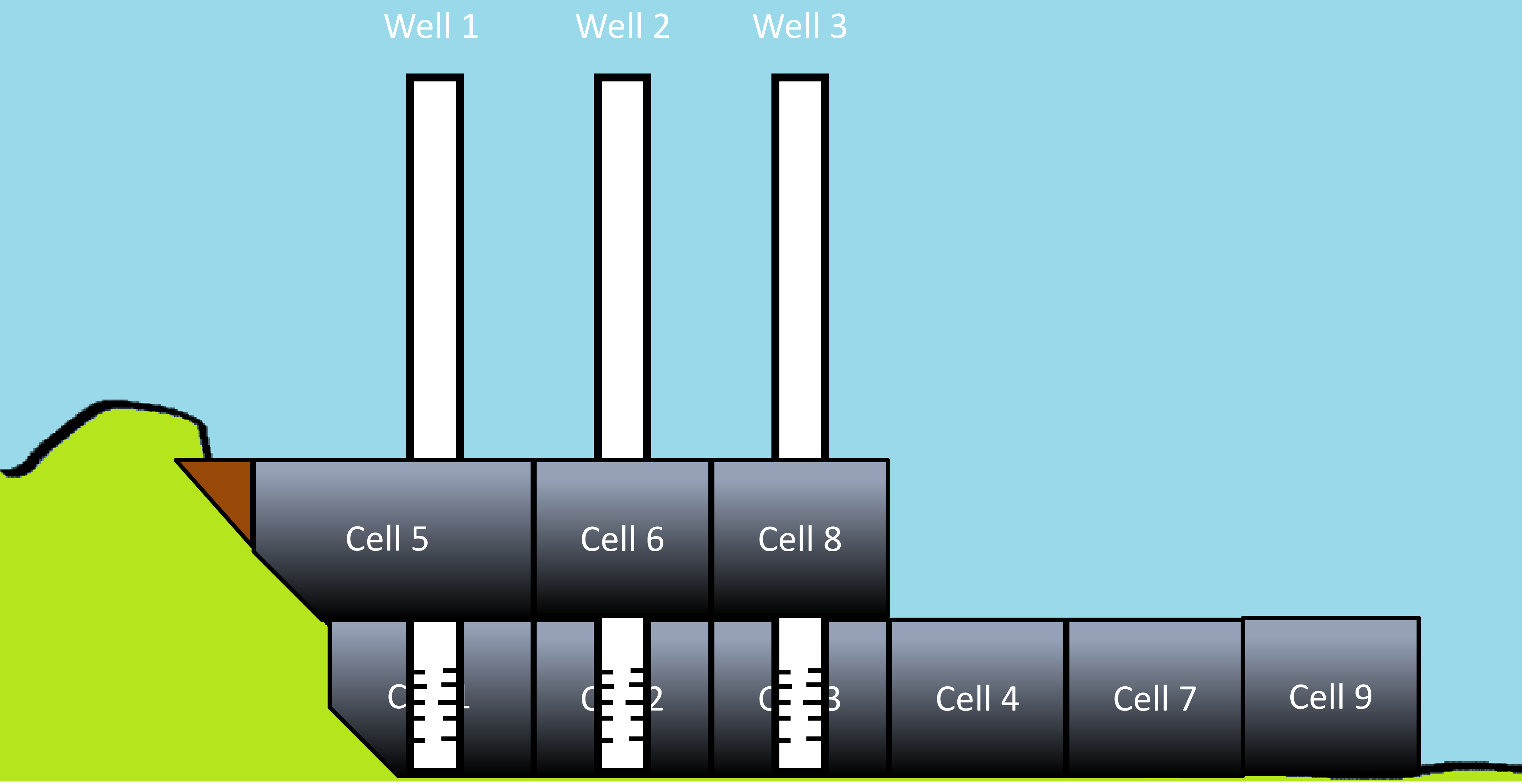
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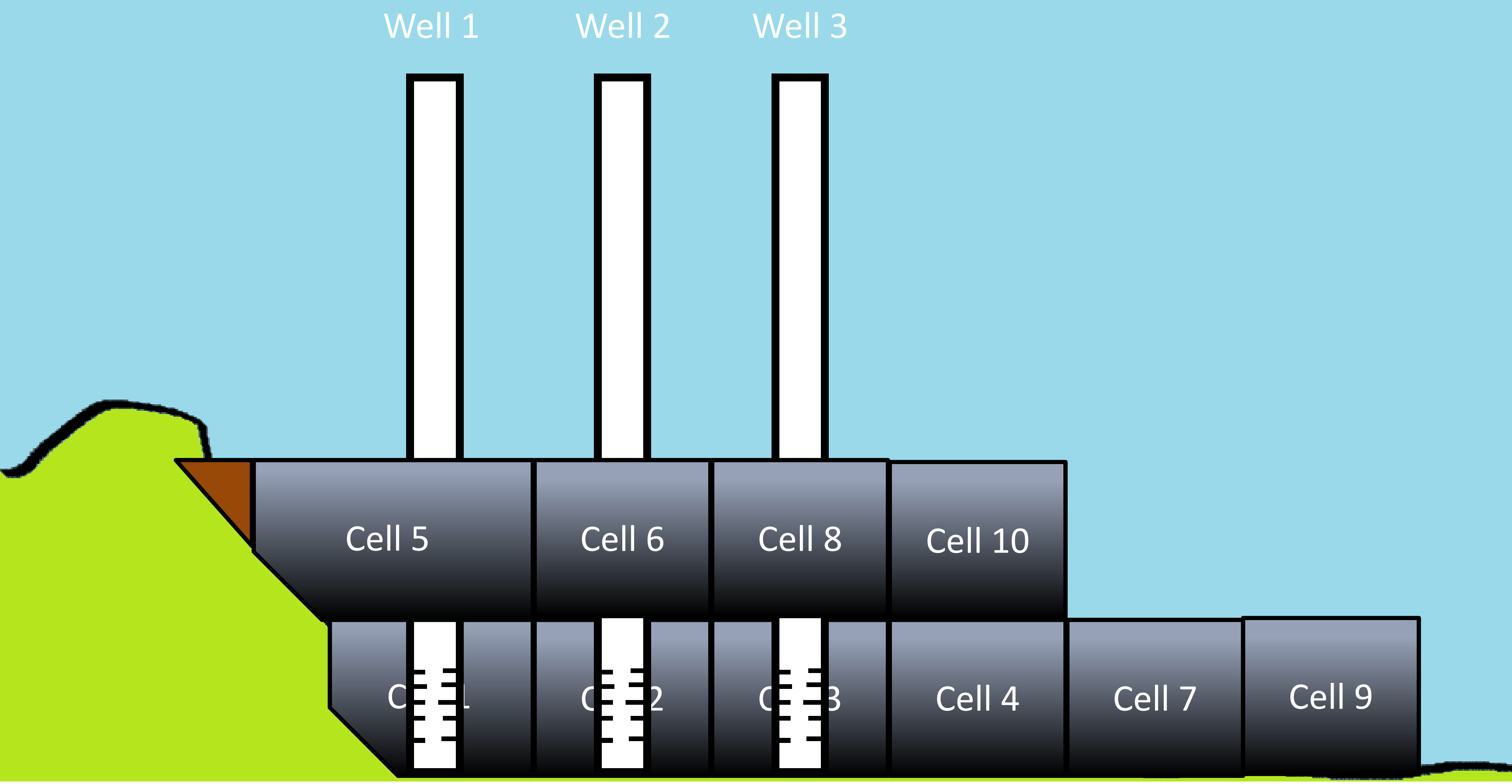
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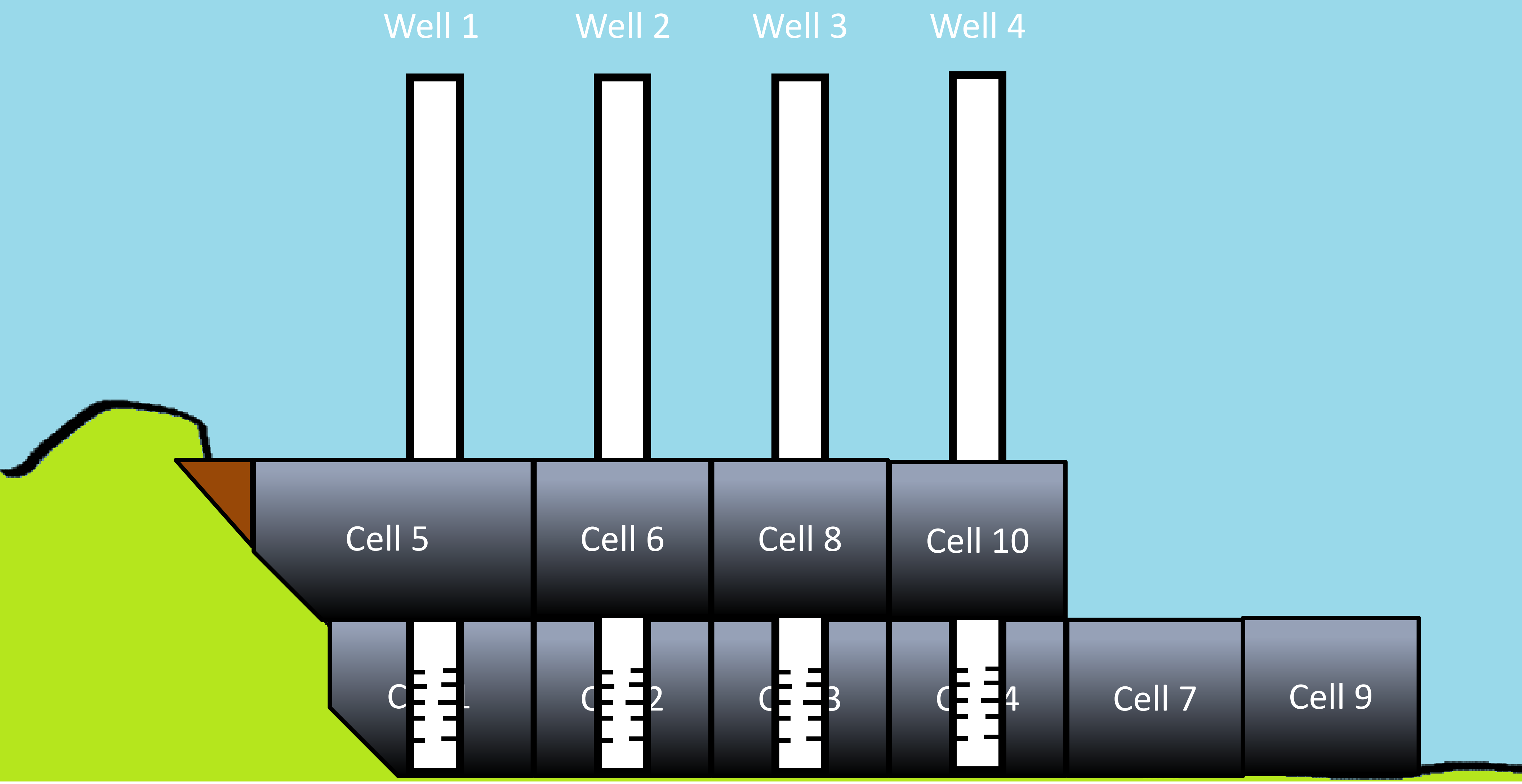
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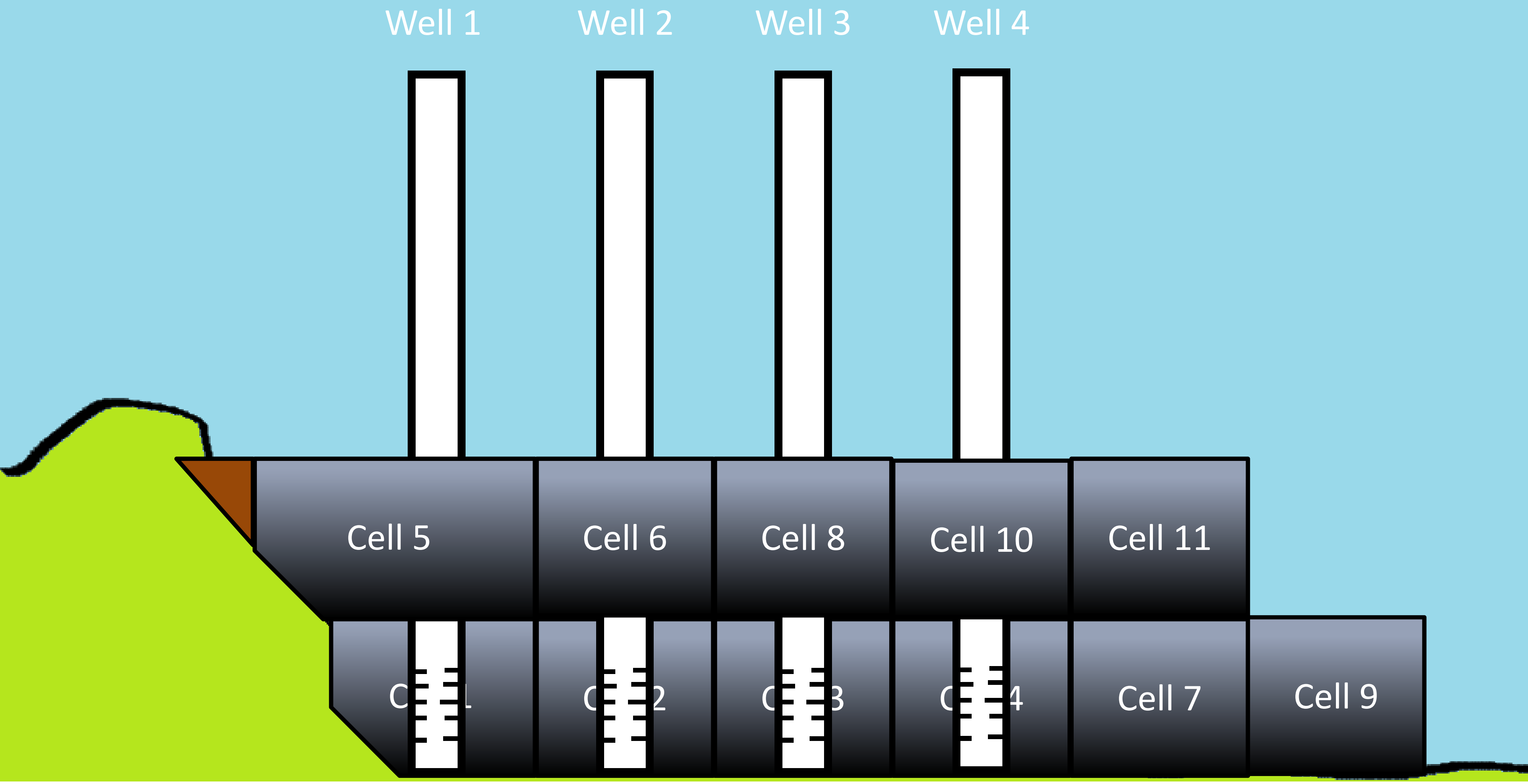
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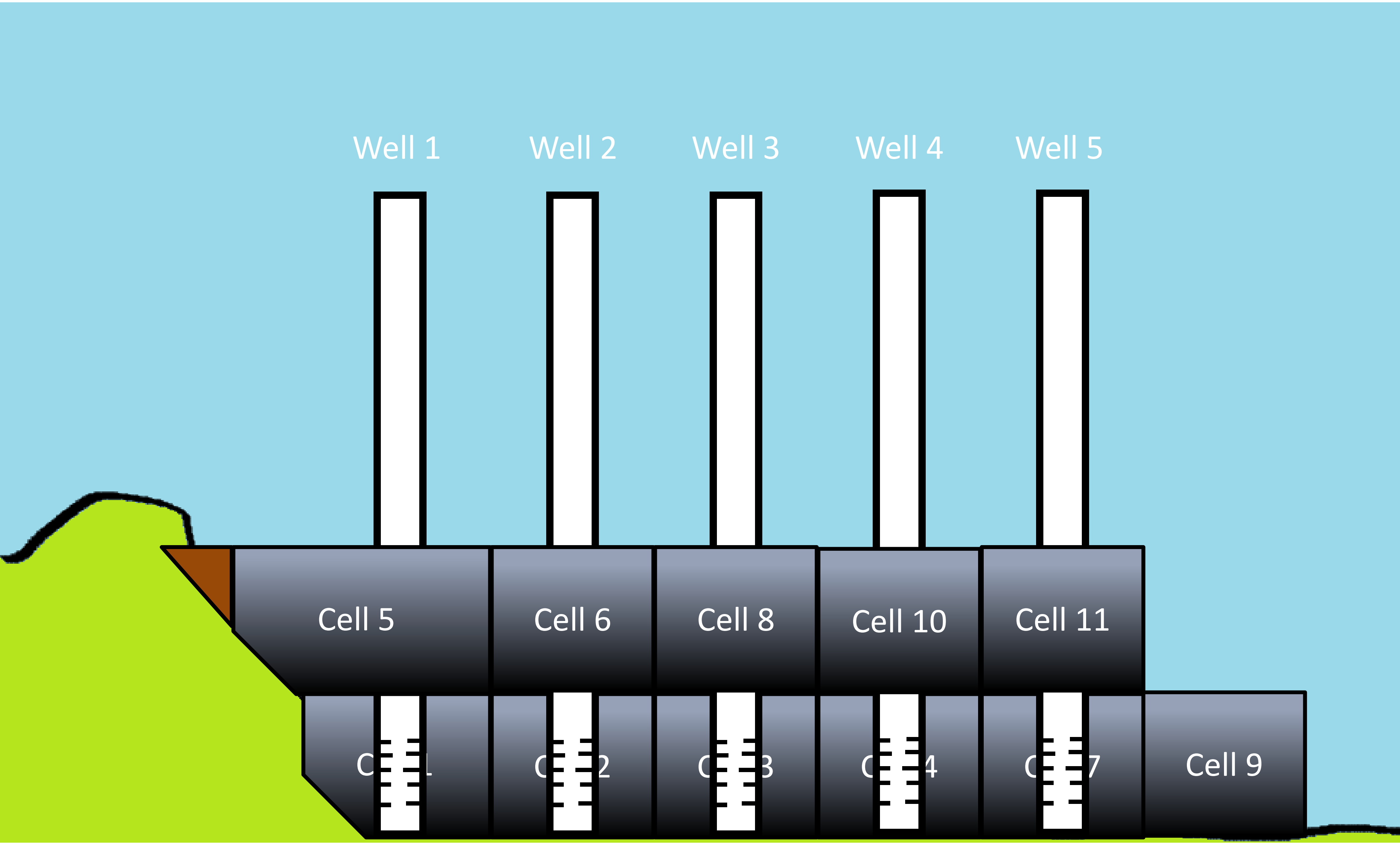
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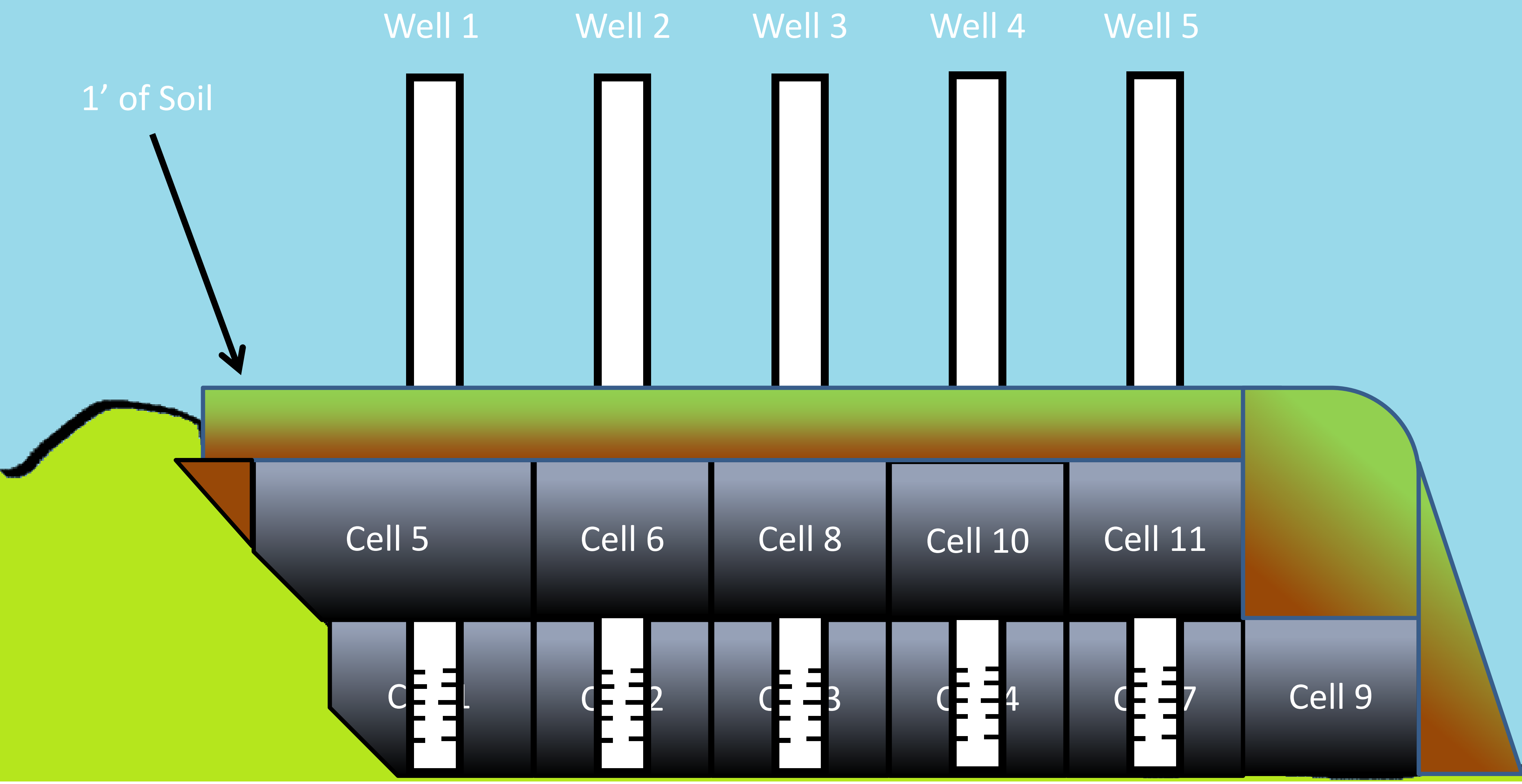
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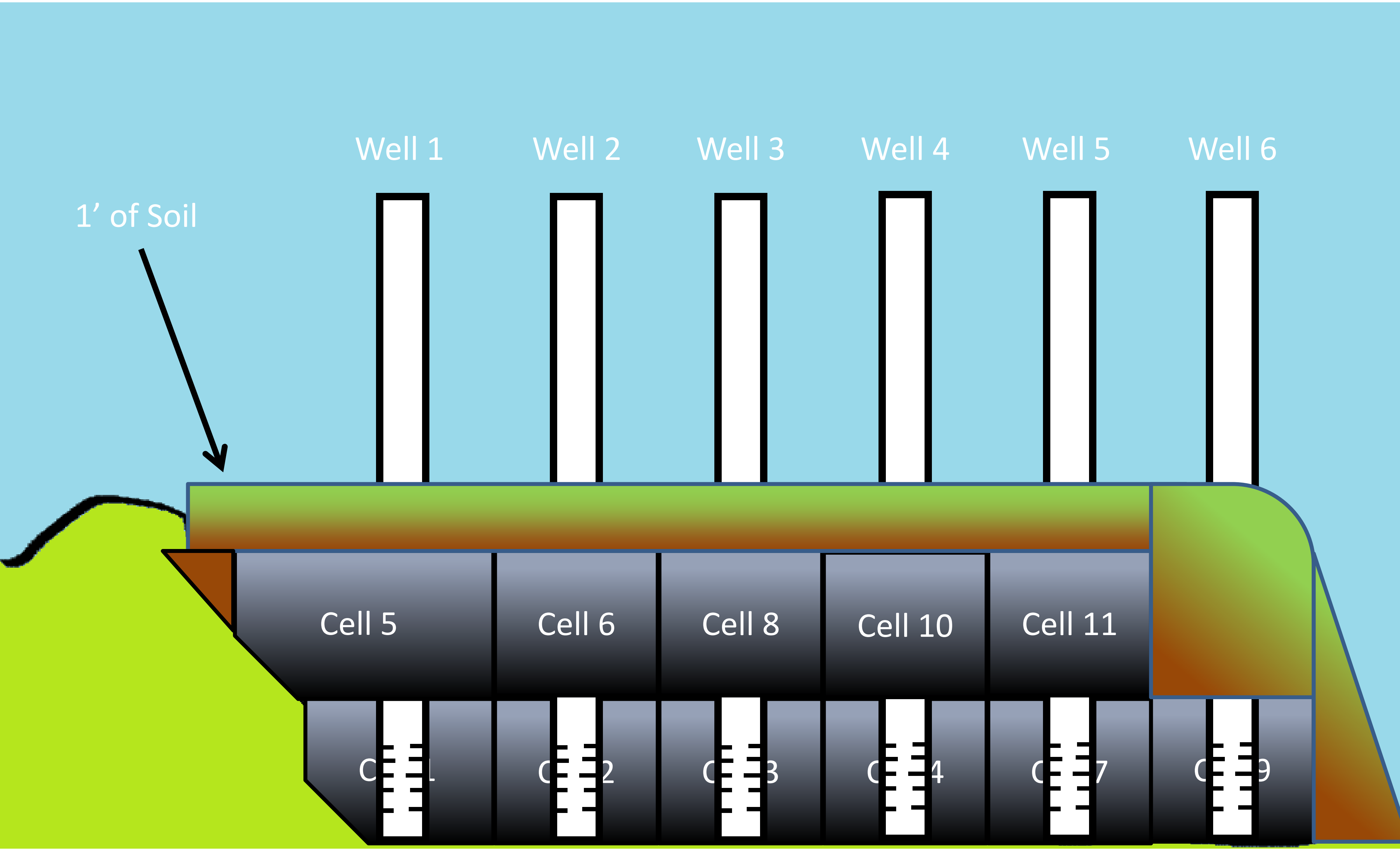
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Cell 10
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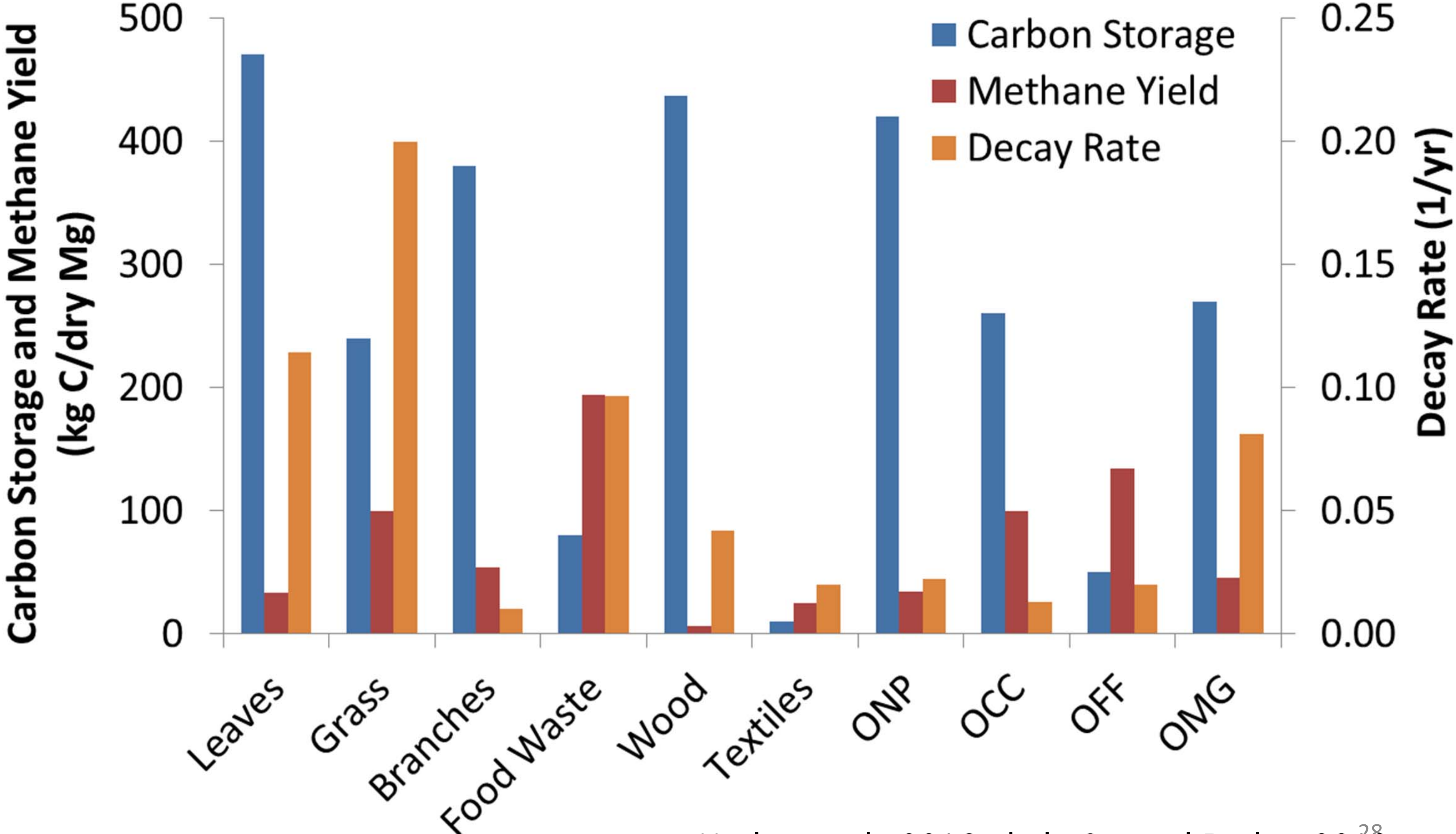
Analyzing Waste in Typical Landfills or a Specific Landfill

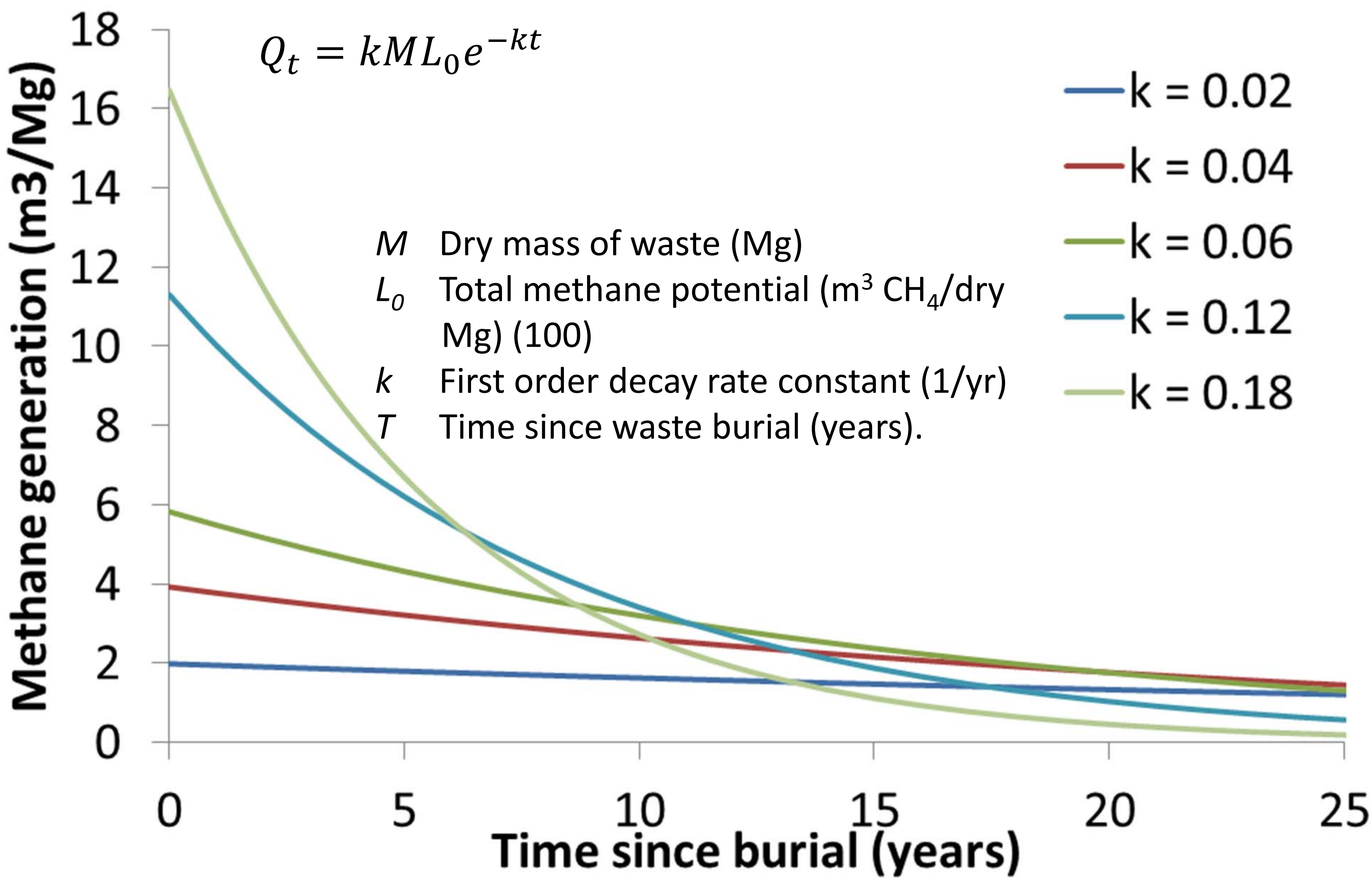
- The LCA goals must include a decision on whether to model a specific landfill or a “typical” or “average” landfill.
  - A city or county may model their specific landfill.
  - A waste generator or product manufacturer may model “average” landfills because their products could be disposed in any landfill.
- The SWOLF framework is capable of modeling a ton of waste in a specific or average landfill

Material Properties



Hodge et al., 2016; de la Cruz ad Barlaz, 2010

Landfill gas modeling - Effect of decay rate on methane generation



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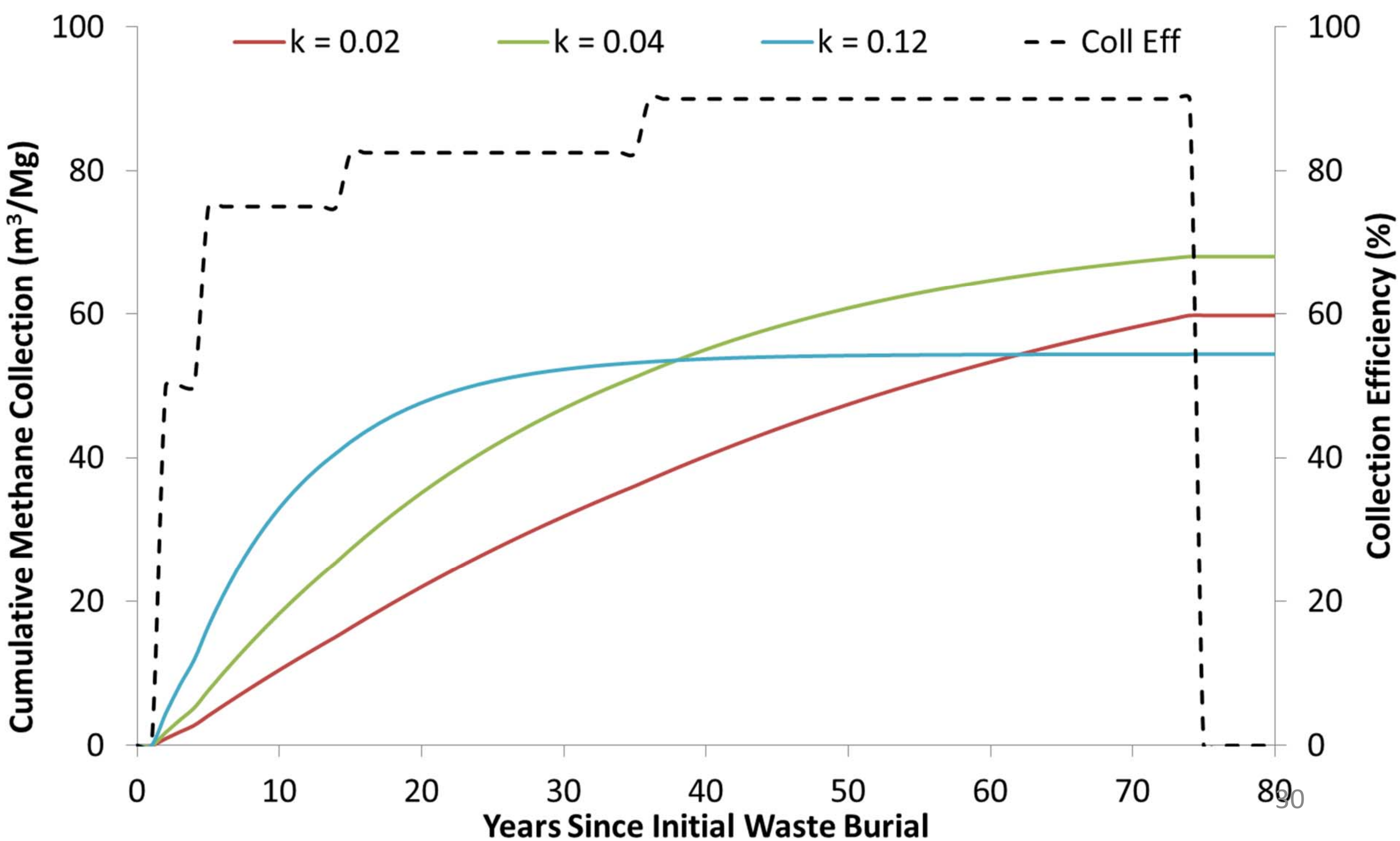
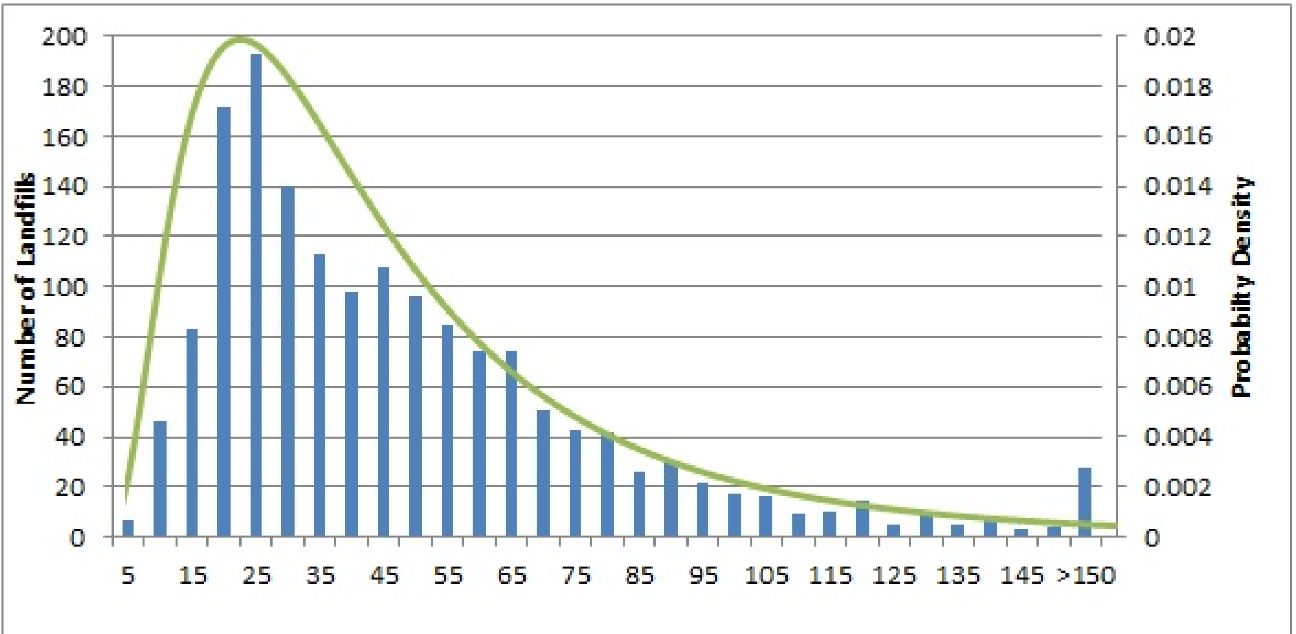
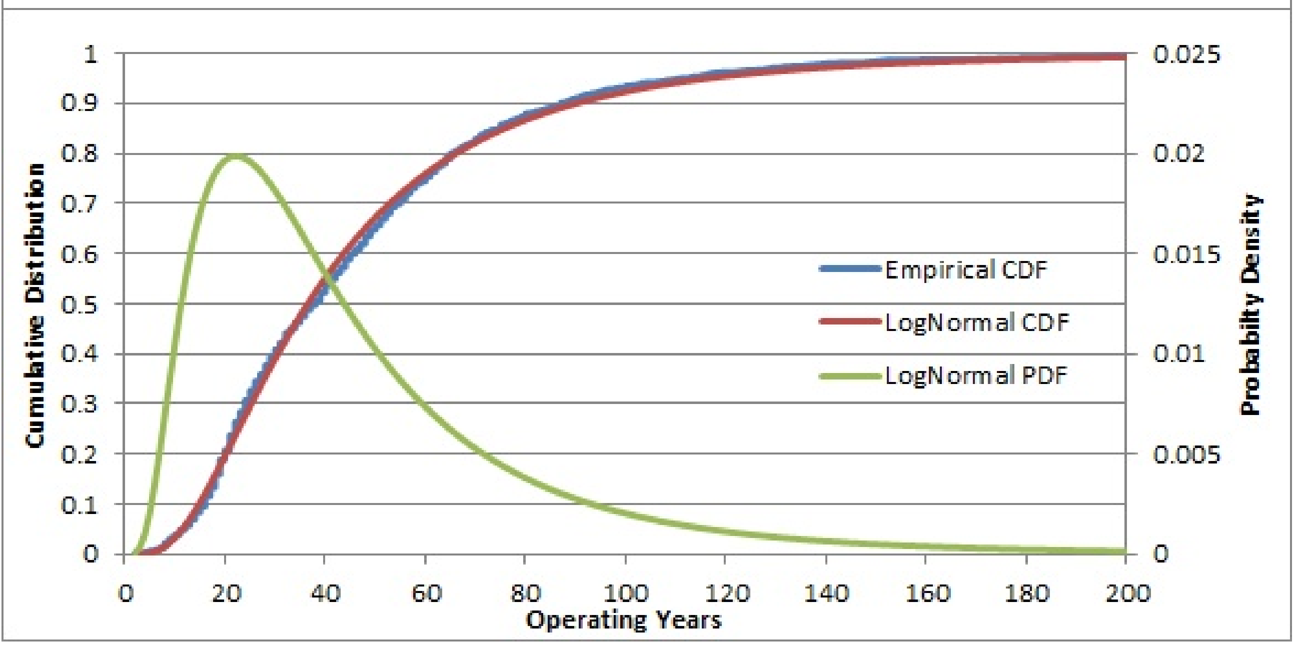
Effect of decay rate on methane collection

- L_0 = 100 m^3/wet Mg
- Values for waste buried in first year.
- Collection efficiency varies with time, decay rate, and landfill operation.



How Long Do Landfills Operate?





- Length of operations affects total landfill gas generation and collection.
- Flare and beneficial use are dependent on gas collection.
  - Flare CAA requirements
  - Ability to run engines

Data (landfills w/ at least 100,000 tons in place)

Mean – 46.6

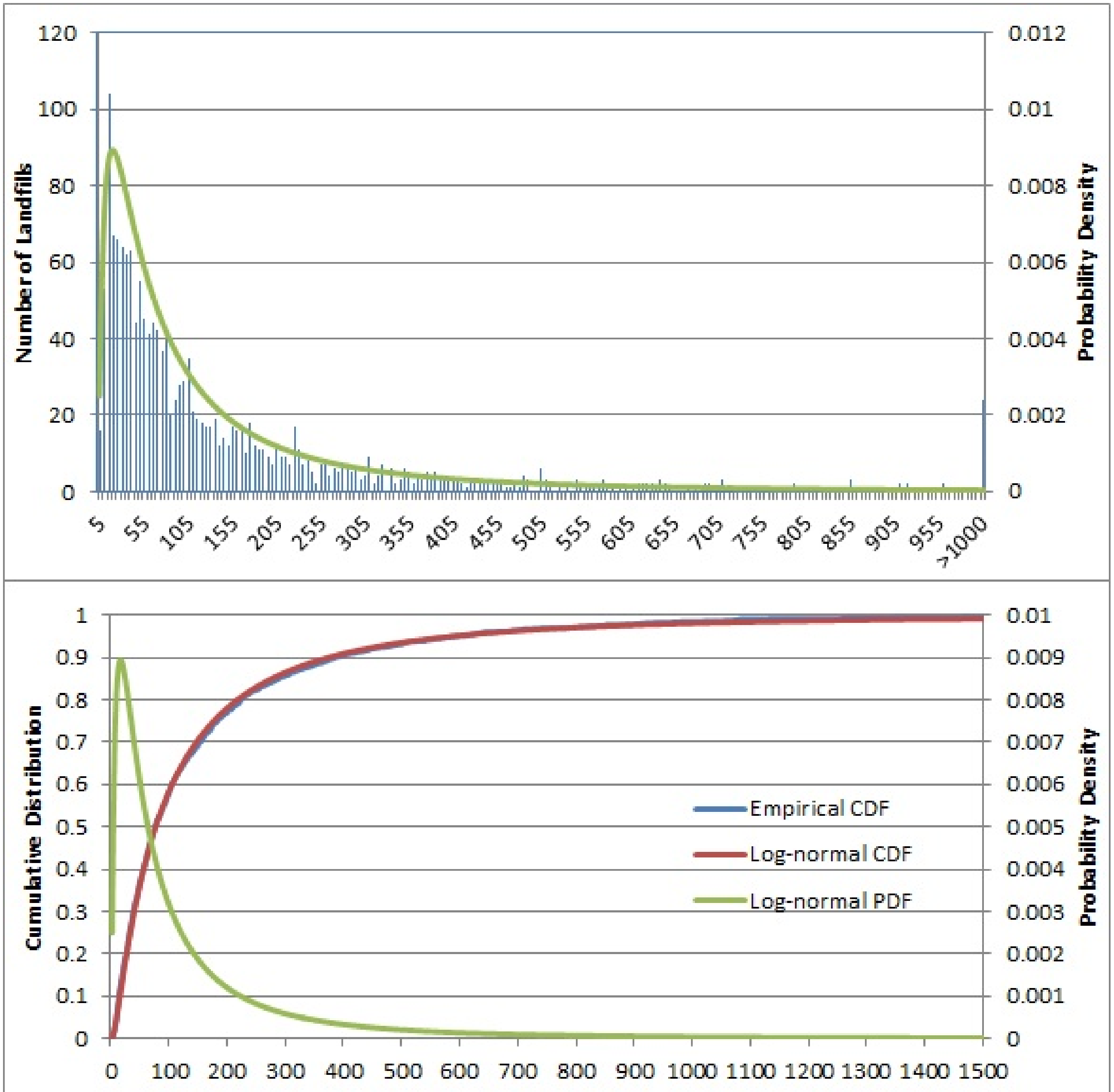
StDev – 37.4

10th percentile – 16

Median – 38

90th percentile – 87

How Big is a Landfill?



Annual Waste Acceptance (1000 tons per year)

- Annual waste acceptance affects total landfill gas generation and collection.
- Flare and beneficial use are dependent on gas collection.
  - Flare CAA requirements
  - Ability to run engines

Data (landfills w/ at least 100,000 tons in place)

Mean – 159 (1000 tpy)
StDev – 236
10th percentile – 14
Median – 77
90th percentile – 385

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Landfill gas collection scenarios

Data values developed based on discussions among the WARM Landfill Working Group

Parameter	Aggressive	Typical	CAA Min	CA Regs
Time until initial gas collection (yr)	0.5	2	5	1
Initial gas collection efficiency (%)	50	50	50	50
Time to increased gas collection efficiency (yr)	3	5	5	2
Increased gas collection efficiency (%)	75	75	75	80
Time from initial waste placement to long term cover (yr)	15	15	15	8
Gas collection efficiency under long term cover (%)	82.5	82.5	82.5	85
Time from final waste placement to final cover (yr)	1	1	1	1
Gas collection efficiency under final cover (%)	90	90	90	90
Collection System Downtime (%)	3	3	3	1.1

Flare and Energy Recovery Operational Parameters

Flare Cutoff Criteria	Aggressive	Typical	CAA Min	CA Regs
NMOC Emissions Cutoff (Mg/yr)	50	50	50	50
Minimum Operation Time (yr)	16	16	16	16
Collected LFG Cutoff (cfm)	-	-	-	100

Energy Recovery Parameters (all scenarios)

- Minimum LFG collection flow rate for energy recovery – 350 cfm
- Time above 350 cfm required before energy recovery begins – 1 yr
- Total time above 350 cfm required for energy recovery – 5 yrs

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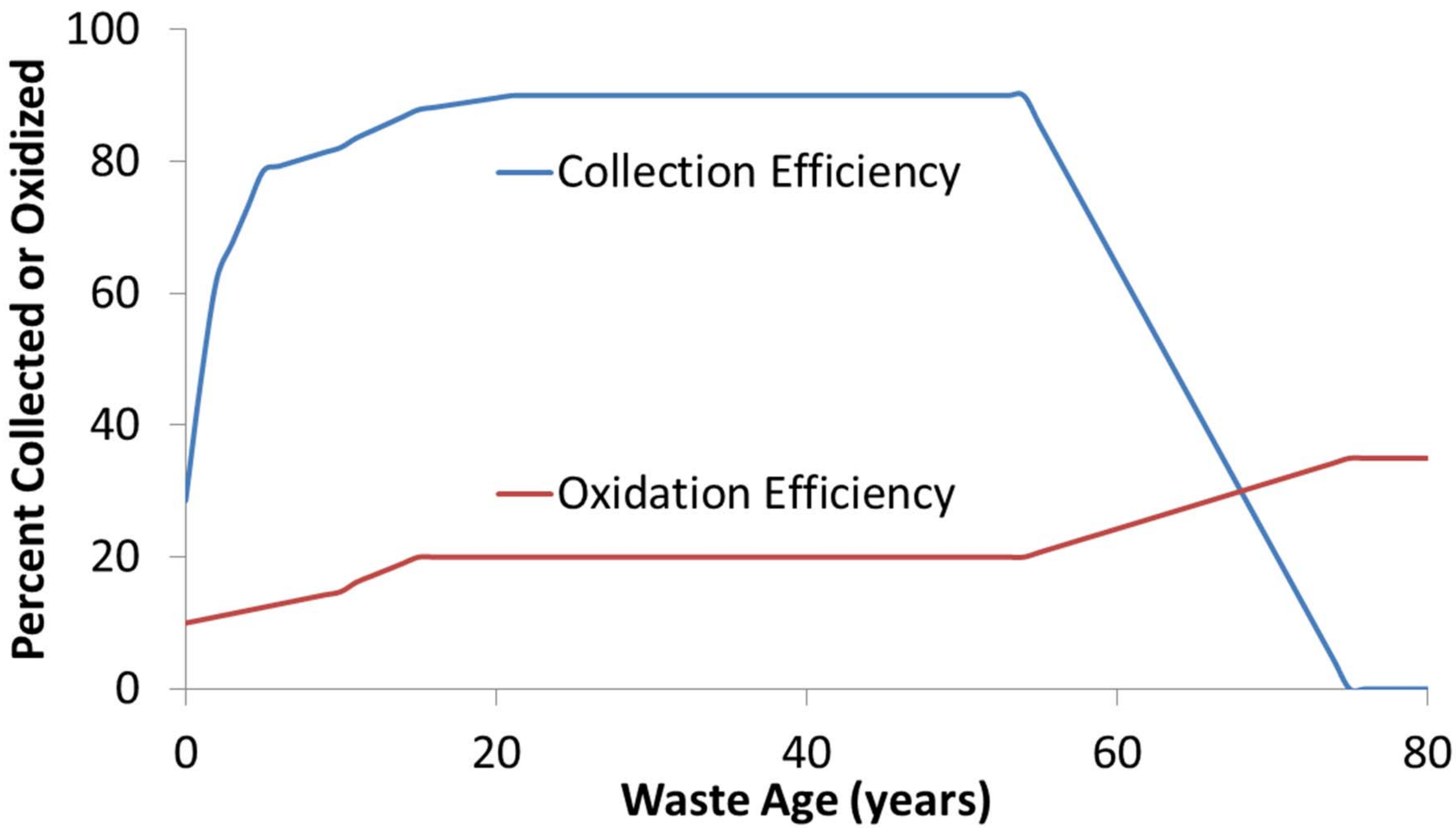
Oxidation Parameters

- Percent oxidation values were developed based on new EPA guidance.
- Rates reflect the fact that
  - Percent oxidation is a function of methane flux (g CH_4/m^2-s)
  - Flux is of collection efficiency and methane generation rate (g CH_4/kg waste)
  - Collection efficiency and methane generation rate are functions of time

Oxidation Situation	Value (%)
Without gas collection or final cover	10
With gas collection before final cover	20
After final cover installation	35

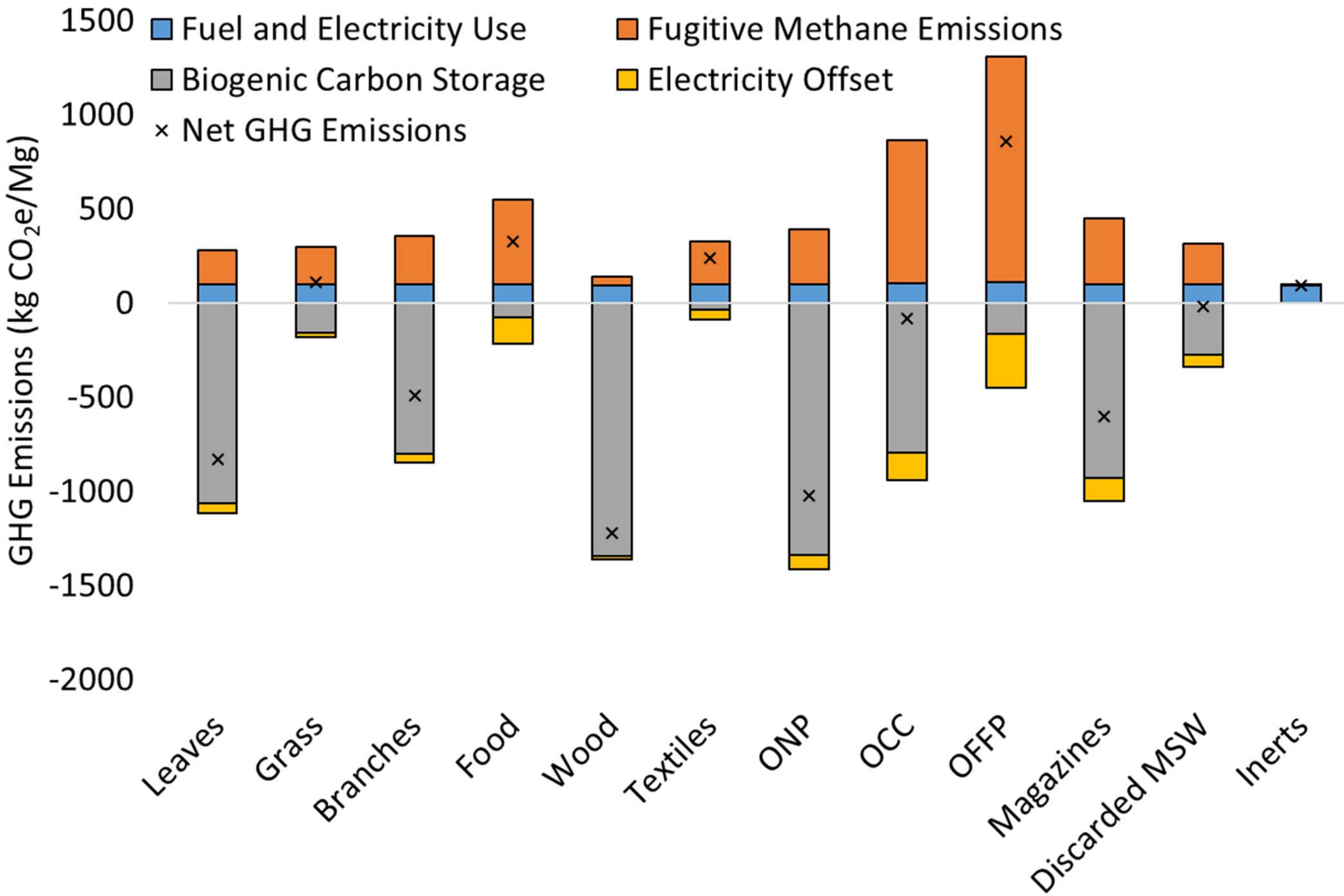
Temporally Averaged Waste Age Landfill Gas Collection and Oxidation Efficiency

- 200,000 tons/yr
- 35 year operation
- Typical gas collection
- Gas collection ceases at year 75 (not enough gas to generate electricity)



Illustrative Results

k = 0.04 yr^{-1}
Typical Gas Collection



Model Implementation

- Ran 2000 Monte Carlo simulations with randomly selected operating life and waste acceptance
- Modeled four (4) collection scenarios with and without beneficial energy recovery.
  - Aggressive Collection (Aggressive)
  - Typical Collection (Typical)
  - CAA Regulatory Minimum Collection (CAA Min)
  - California AB-32 Regulatory Collection (Cali Regs)
- Modeled four (4) bulk decay rates
  - $k = 0.02, 0.04, 0.06, 0.12\ yr^{-1}$
  - Influences waste component decay rate

Model Implementation

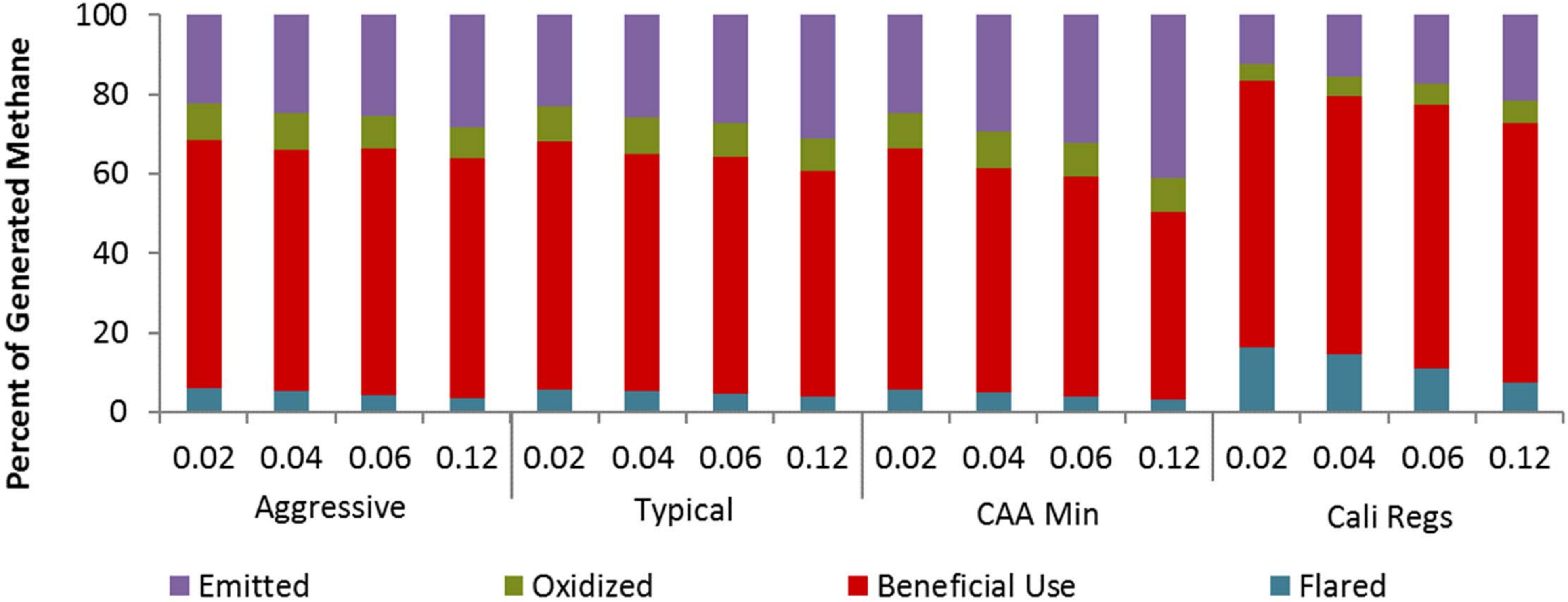
- Modeled 12 degradable waste components
  - Branches
  - Grass
  - Leaves
  - Food Scraps
  - Corrugated Cardboard
  - Magazines/3rd Class Mail
  - Newspaper
  - Office Paper
  - Lumber
  - Medium-density Fiberboard
  - Wood flooring
  - Mixed MSW

U.S. Landfill Population

Landfill type	Annual Precipitation (cm)[a]	Decay Rate (yr^{-1})[a]	Percent of Waste Received[b]
Arid	<51	0.02	20.0
Moderate	51 < x <102	0.04	28.9
Wet	>102	0.06	41.1
Bioreactor	N/A	0.12[c]	10.0

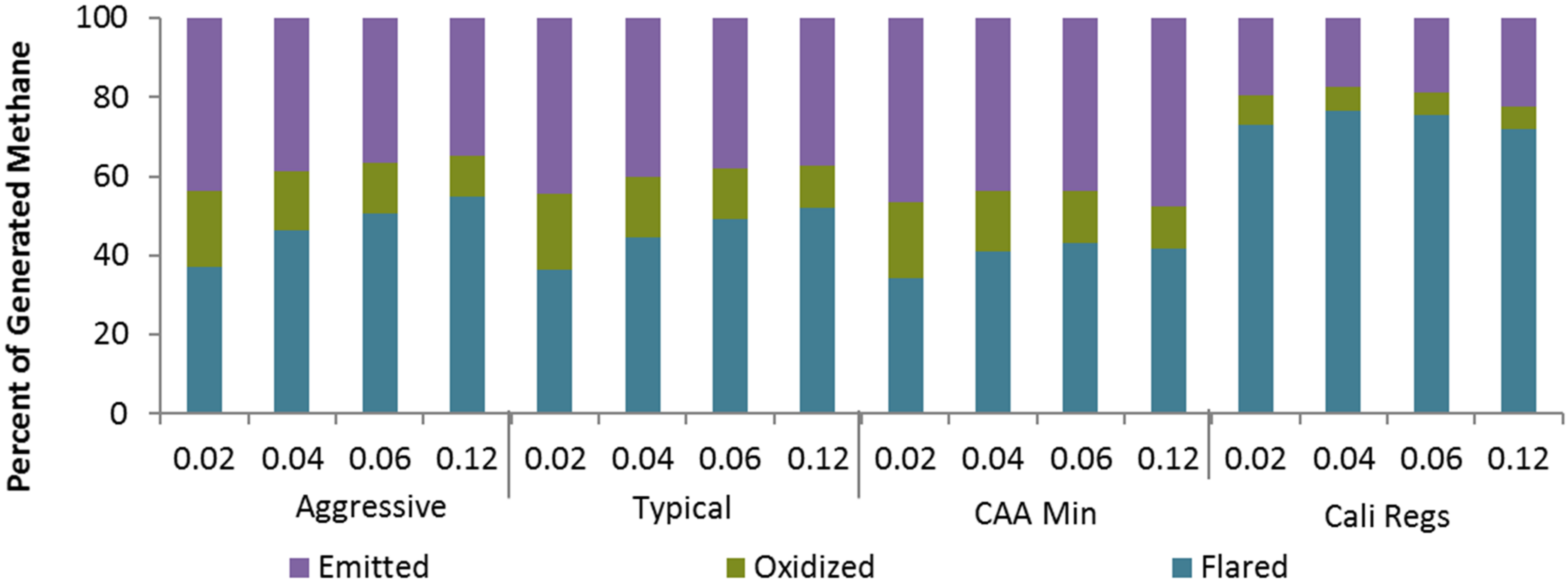
a. From U.S. EPA, 2010.
b. Adjusted based on U.S. EPA, 2010 based on assumption of 10% in bioreactors
c. Judgment based on values reported in Barlaz et al., 2010 and Tolaymat et al., 2010.

Results – Mixed Waste w/ Energy Recovery



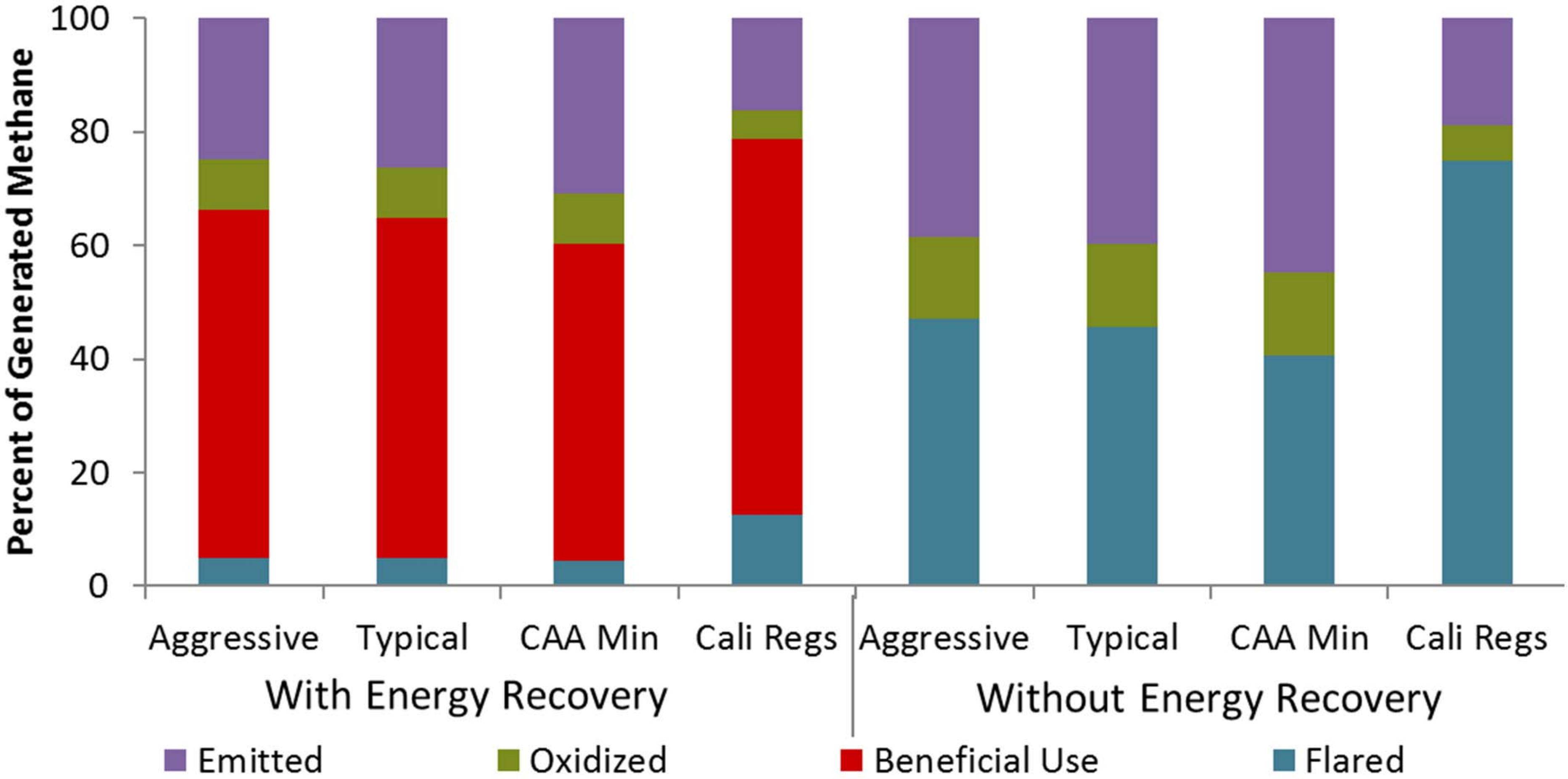
- 12-41% of generated methane is emitted (22-41% outside California).
- Increasing decay rate leads to greater emissions.
- Little difference between Aggressive and Typical collection scenarios.
- California regulations significantly decrease emissions.
- Collected gas results in energy offsets while emitted gas represents a greenhouse gas emission

Results – Mixed Waste w/out Energy Recovery



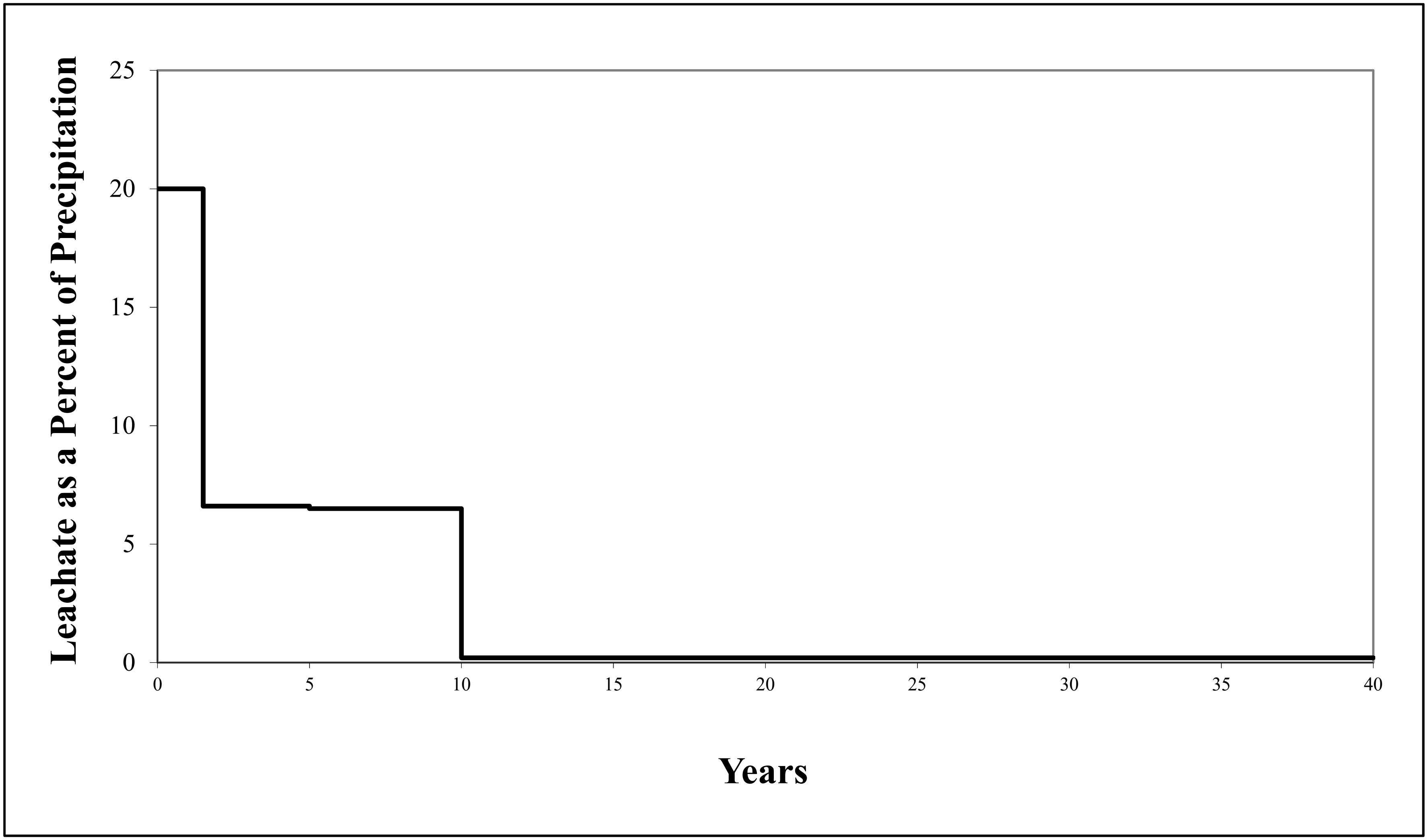
- 17-48% of generated methane is emitted (34-48% outside California).
- Emissions increase by 7 to 22% over Energy Recovery scenario for non-California scenarios
  - More at lower decay rates
- Effect of decay rate is more complicated
  - Faster decay is better in Aggressive and Typical.
  - Decay rate of 0.04 and 0.06 best in CAA Min and CA Regs scenarios

National Average Landfill Gas Emissions



- For landfills with energy recovery, Californian regulations decrease fugitive emissions by 35-50% by increasing effective collection efficiency by 12-18%.
- For landfills without energy recovery, Californian regulations decrease fugitive emissions by 51-57% by increasing effective collection efficiency by 27-34%.

Leachate Generation



Alternative would be to assign a value in liters/ha-day that varies with time and climate

Leachate Collection Periods: Length of time and % of Leachate Collection for Treatment

Period	Time (yr)	Traditional	Leachate Recirculation Landfill	Ash
1: After waste placement and before recirculation	1	0	0	0
2: During landfill operations	1-20	100	0	100
3: After landfill closure	21-100	100	100	100
4. Between some time post-closure and the end of the modeling period	0	100	100	100

User may assume release to the environment or accumulation of leachate

Leachate Composition

- Pollutants that vary with time (BOD) and others that are constant (TSS)
- BOD concentration varies with time
  - Multiply concentration by generation to obtain mass BOD/ton total waste
    - Allocate BOD based on fraction of total gas
      - 0 for plastic, non-zero for food waste
- N and P: derived allocation fractions based on total N and P in leachate from waste component specific lab studies
- Metals: Allocated according to their presence in waste components

Leachate Treatment

- Estimated treatment efficiencies and energy requirements
  - Treated leachate is released to the environment

- Model is formulated so that user can specify release of untreated leachate to the environment

Questions?

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Additional Resources

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