The Status of Bioreactors

Debra R. Reinhart, PhD, PE
University of Central Florida

Bioreactor Defined

"……a sanitary landfill operated for the purpose of transforming and stabilizing the readily and moderately decomposable organic waste constituents within five to ten years following closure by purposeful control to enhance microbiological processes. The bioreactor landfill significantly increases the extent of waste decomposition, conversion rates and process effectiveness over what would otherwise occur within the landfill."

Why Operate a Landfill as a Bioreactor?

- to increase potential for waste to energy conversion,
- to store and/or treat leachate,
- to recover air space, and
- to ensure sustainability

Status

- 1993 - less than 20 landfills recirculating leachate
- 1997 - ~ 130 landfills recirculating leachate
- My estimate - ~ 5% of landfills

Regulatory Status

- EPA permits recirculation of indigenous liquids into landfills with Subtitle D liners
- Some states more stringent
- EPA is considering nonindigenous liquid addition

EPA Concerns

- long-term fate of metals,
- the lack of data that demonstrate the reduction of environmental risk and liability, and
- increased operational requirements
- landfill gas capture,
- leachate treatment and storage,

EPA Concerns- Cont'd

- landfill space and capacity reuse,
- greenhouse gas abatement,
- bioreactor design,
- solid waste density considerations,
- settlement,
- waste pretreatment,
- cover,
- management of amendments.

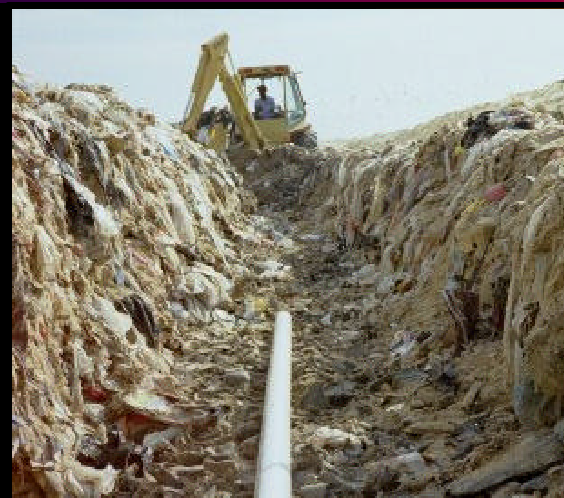
Europe

The European Union Council Directive on Landfilling of Waste has identified the need to optimize final waste disposal methods and ensure uniform high standards of landfill operation and regulation throughout the European Union (EU).

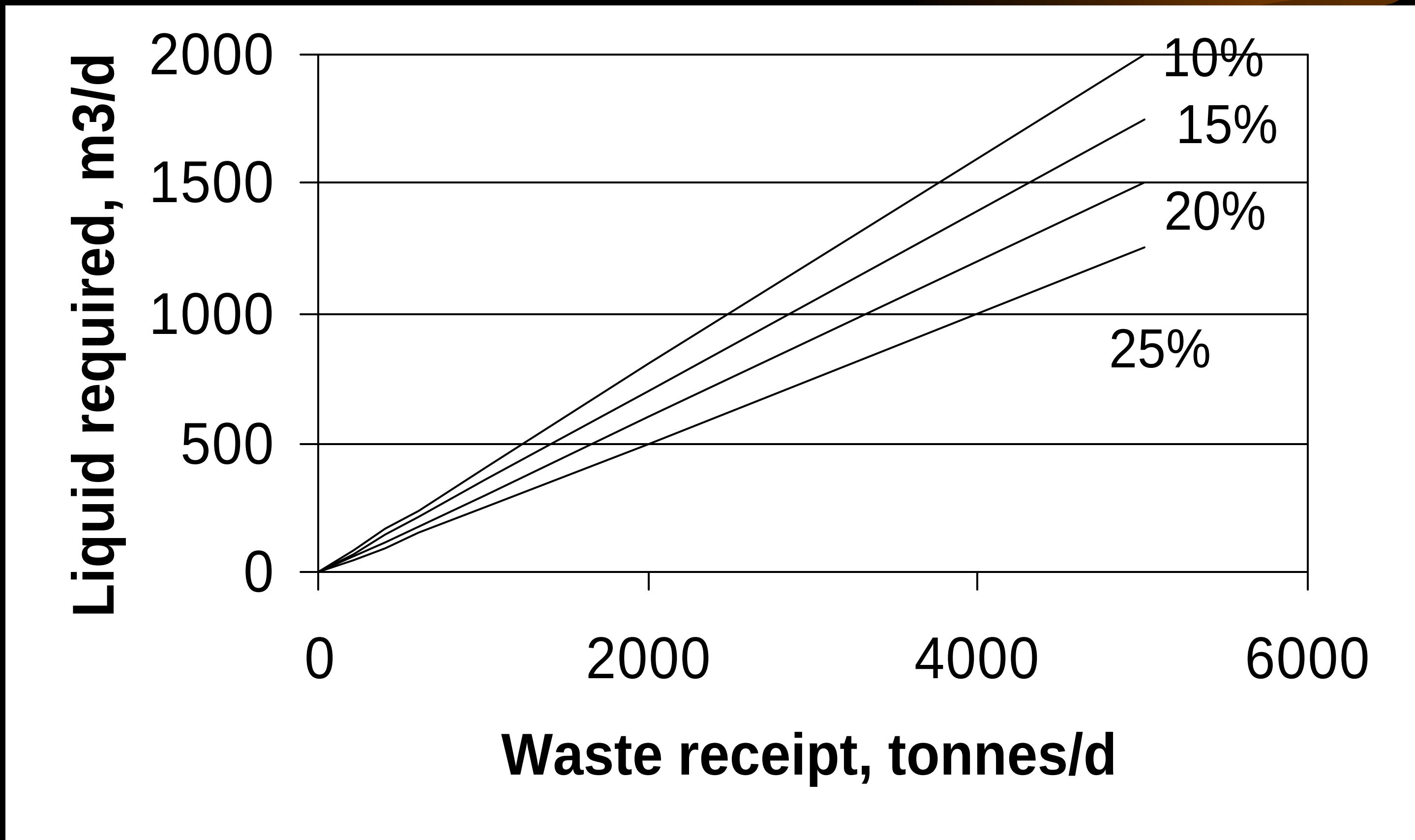
Essential Needs for a Bioreactor

- Composite liner
- Appropriate density of MSW
- Appropriate daily cover
- Leachate recirculation system
- Active gas collection system
- Appropriate final cover sysem
- Competent landfill operator

Leachate Recirculation

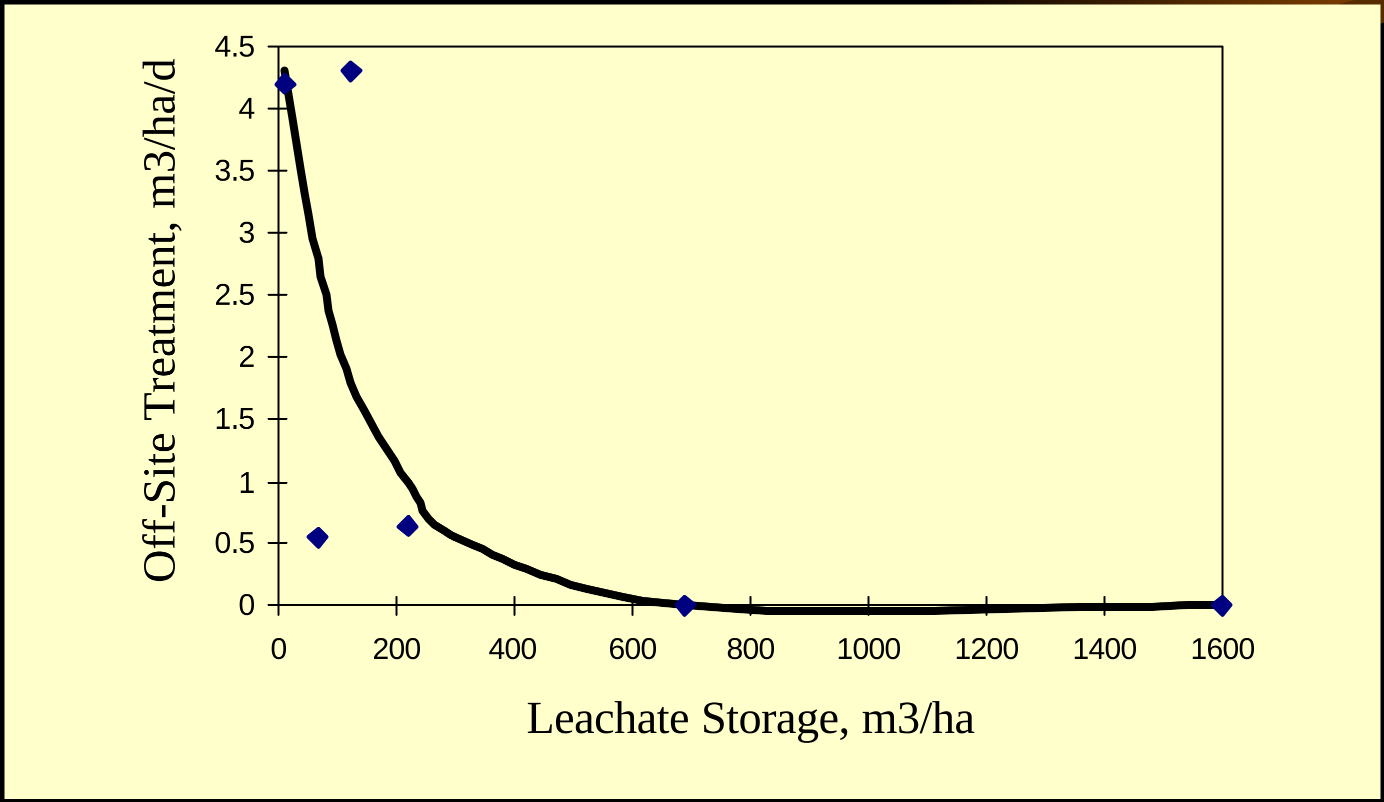


Leachate Quantity



Storage

Leachate Storage Impact on Off-site Treatment



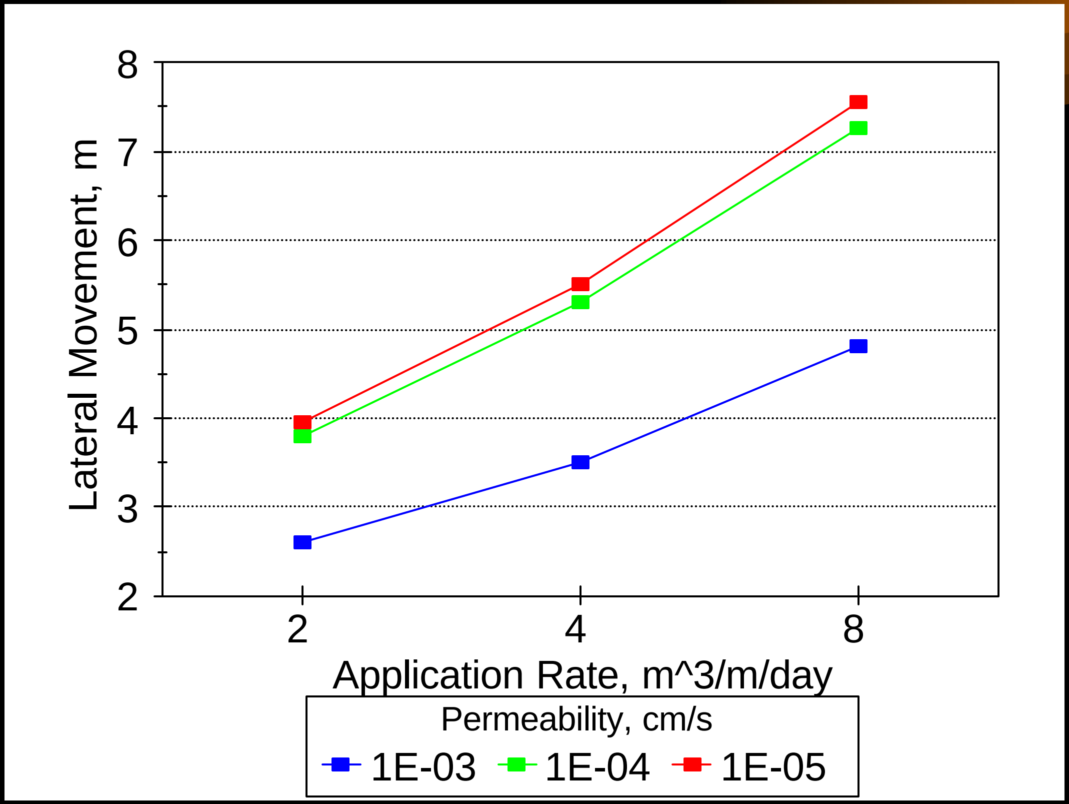
Leachate Collection System Performance

Clogging Potential

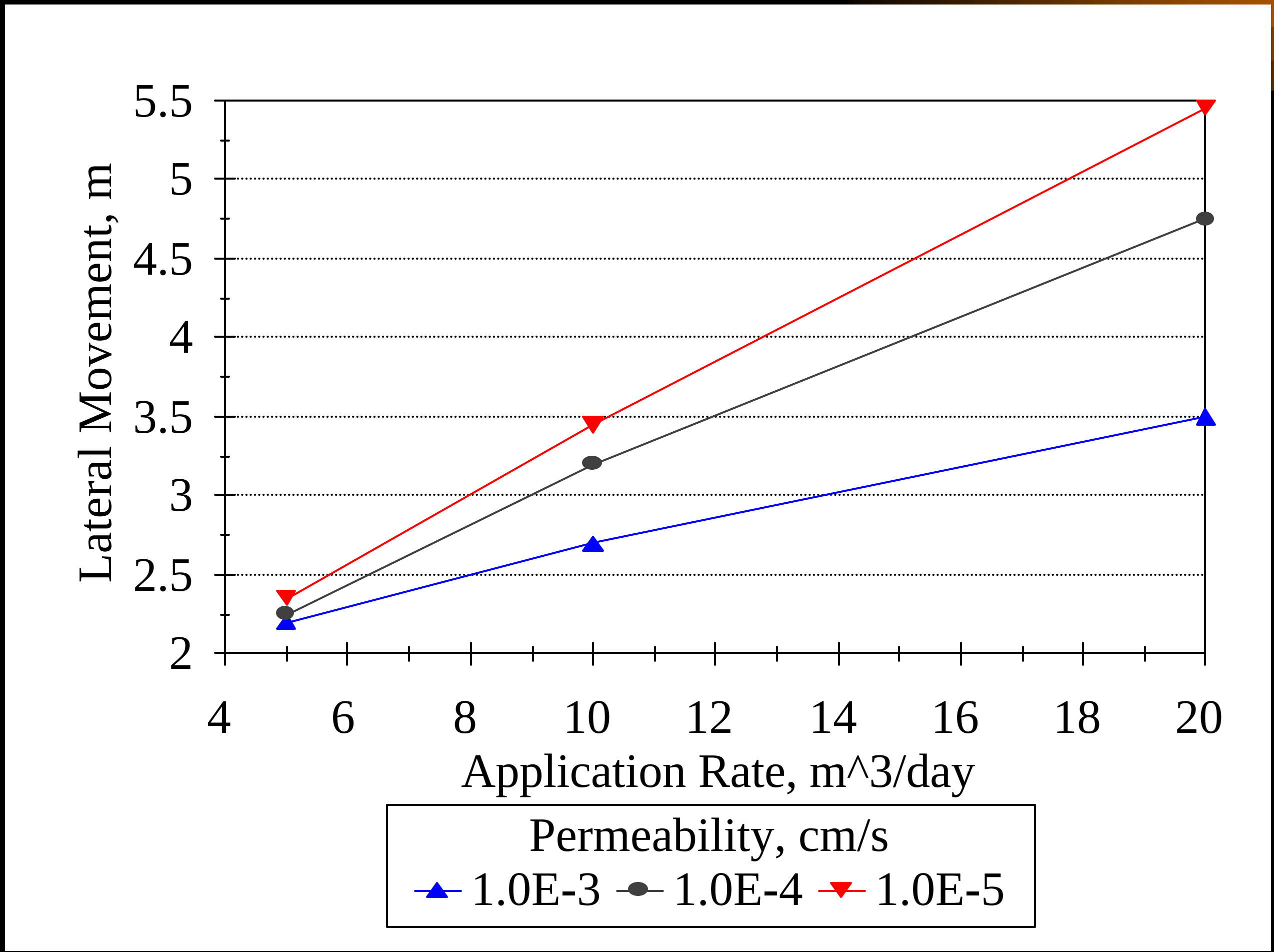
Performance Monitoring

Maintenance

Bioreactor Design - Horizontal Device Placement

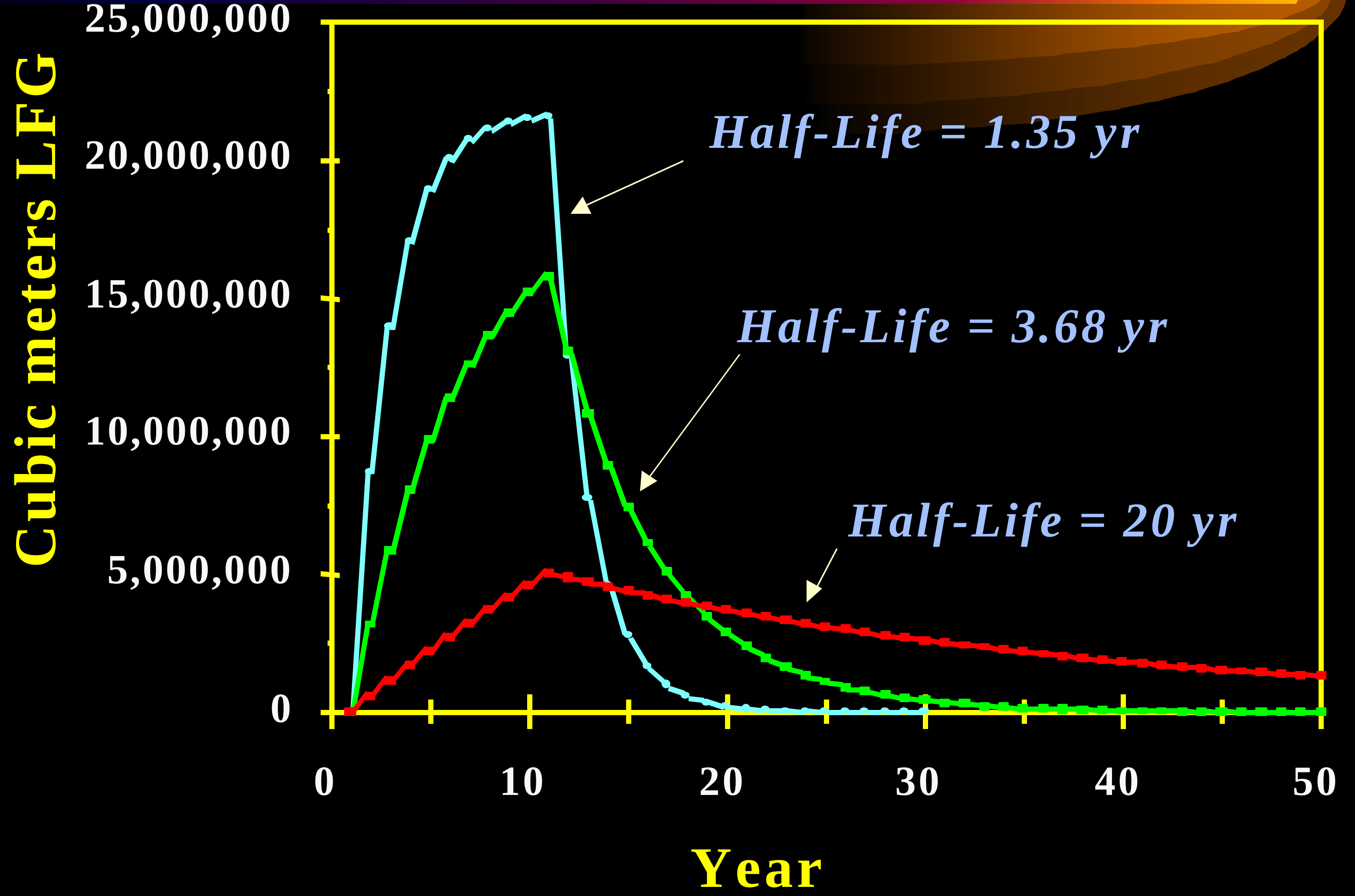


Bioreactor Design - Vertical Well Placement

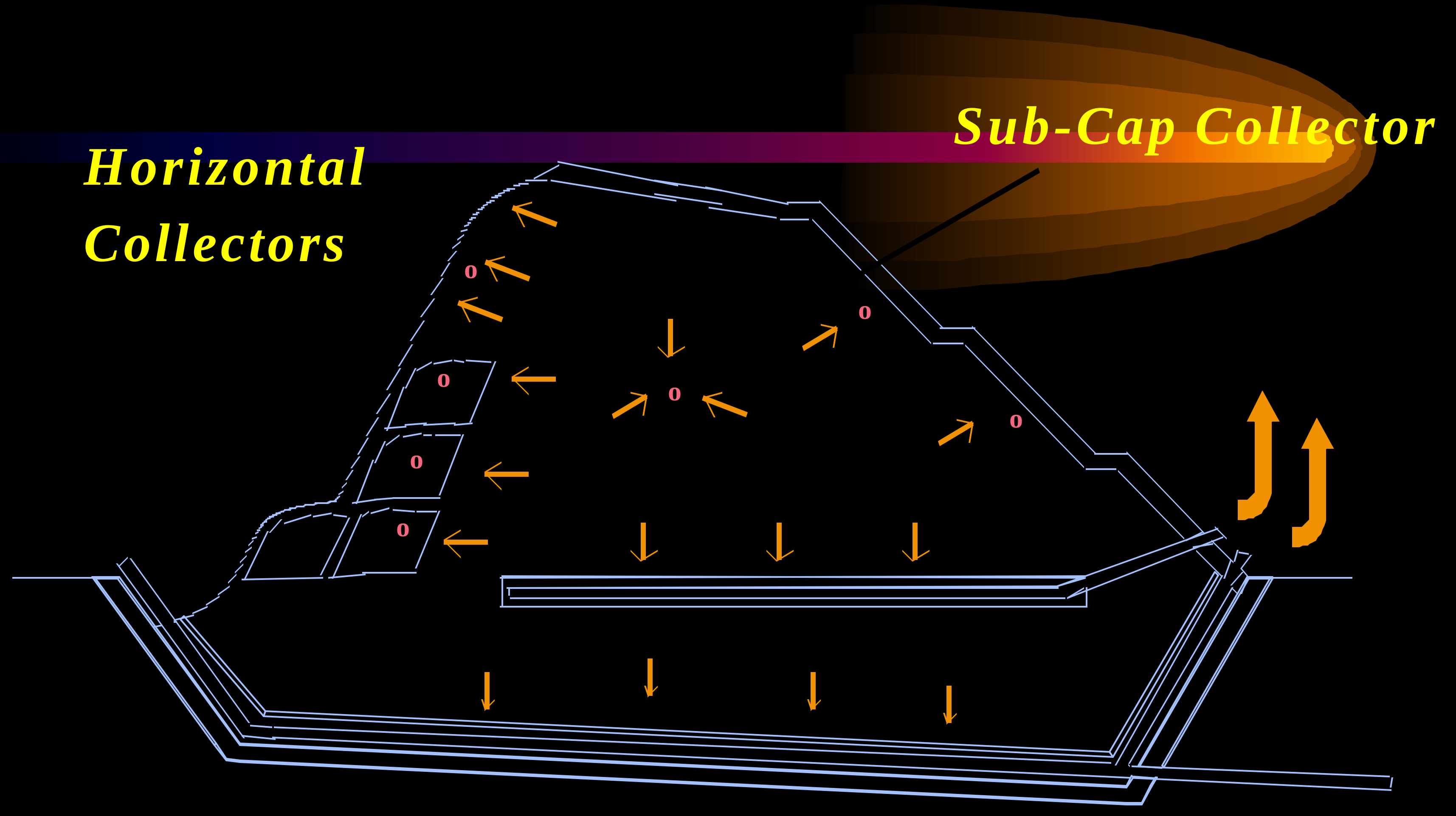


Gas Collection

LFG Generation Curves



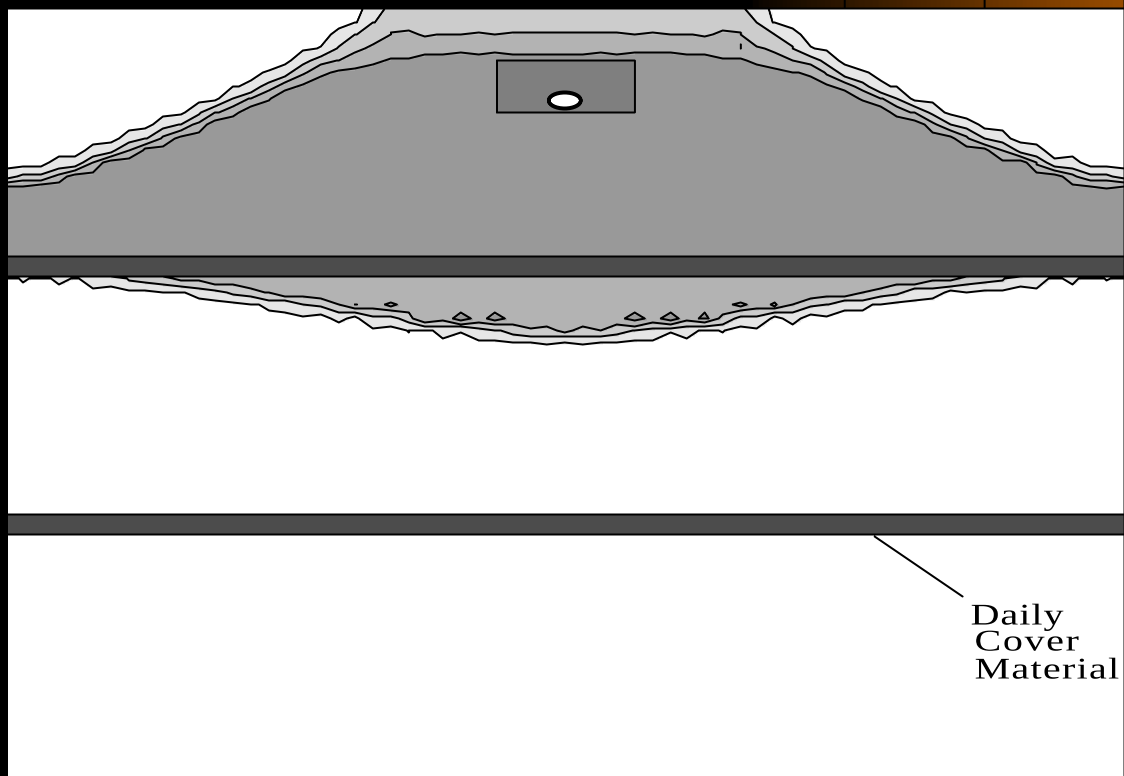
LFG Collection From Operating Landfills



Leachate Collection System - LFG Collector Network

Odor Potential

Cover Issues



Leachate Outbreaks

Alternative Daily Cover

Impact on landfill Operations

Impact on landfill Operations

- Construction (sequencing)
- Location of roads/access
- Monitoring
  - Settlement
  - Side Seeps
  - Odors

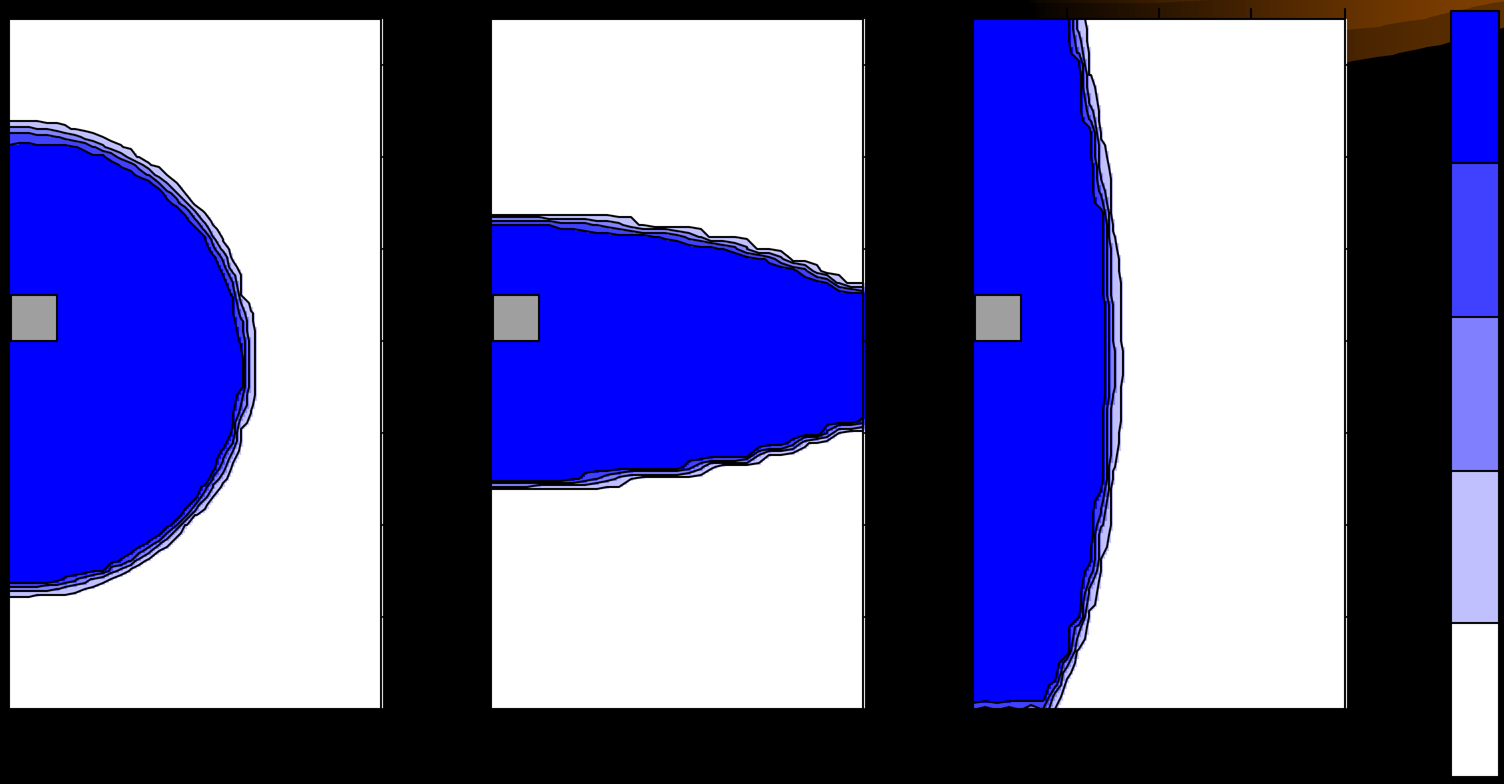
Research Needs

Long Term Sustainability

- Fate of metals
- Fate of other inorganics/recalcitrants
- Flushing bioreactor?

Waste Compaction

Vertical Permeability =10^{-4} cm/s

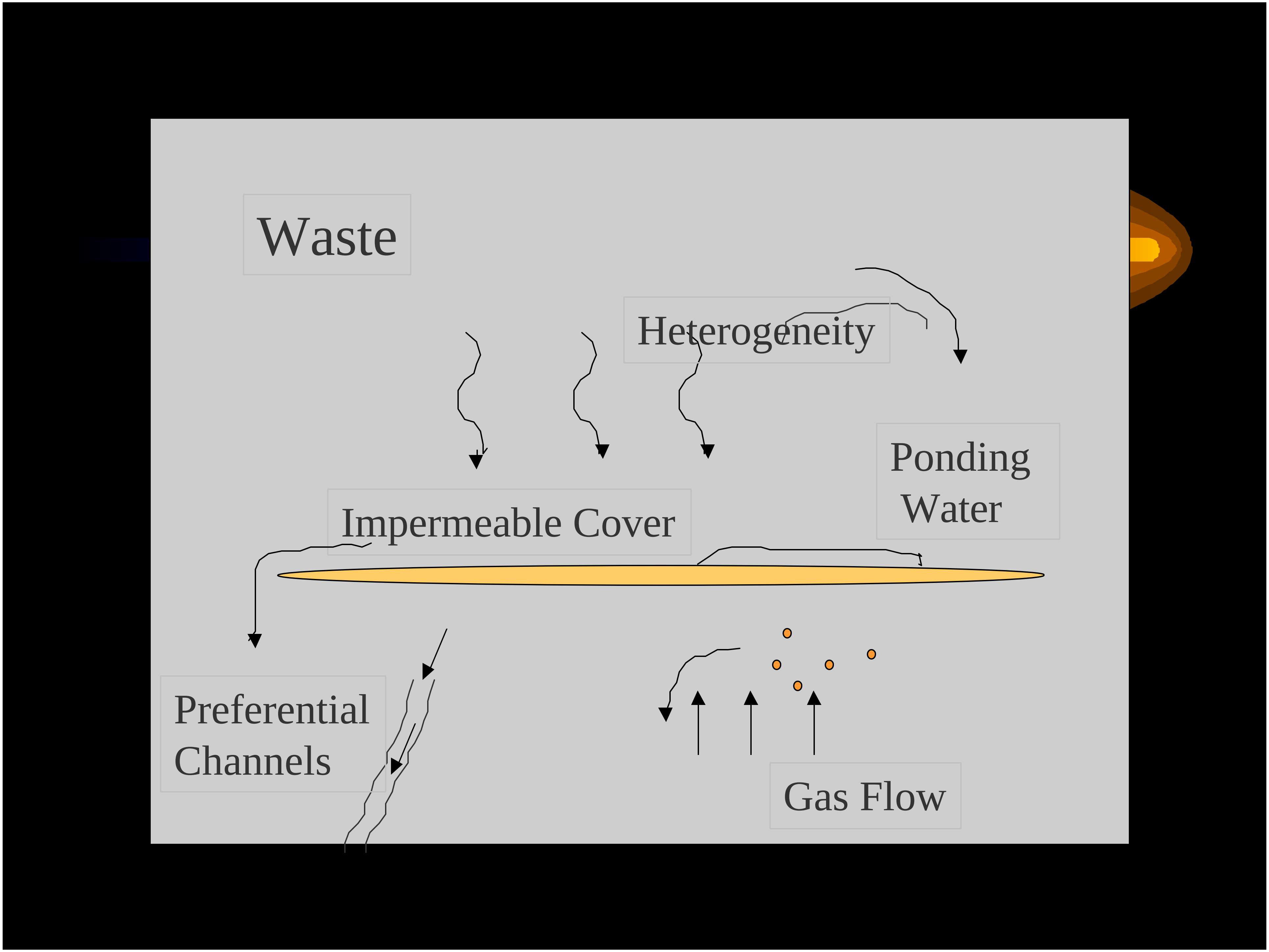


Settlement

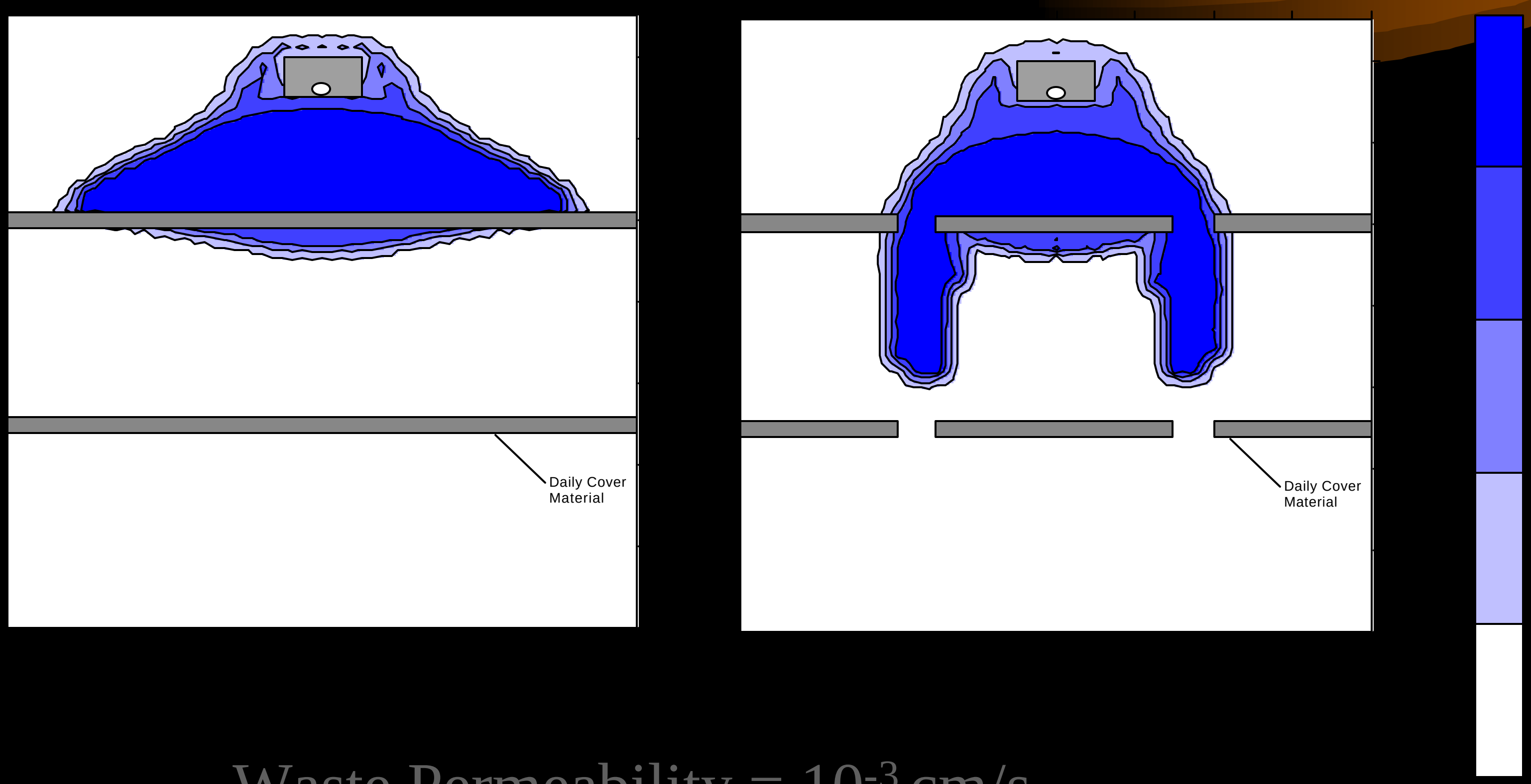
- The Keele Valley Landfill - settlement rates of 10-12 cm/month in wet areas, 5-7 cm/month in dry areas.
- Yolo County, CA test cells - wet cell settlement rates > three times parallel control cell (17 mos)
- lower settlement enhancement (~ 5%) was reported at aerobic cells in Columbia Co
- The Trail Road Landfill in Ontario, Canada reported a 40% recovery of airspace (8 yrs)

Nonindigenous Liquids

- Supplement nutrients and moisture,
- Dispose of liquid waste products,
- Compensate for insufficient leachate volumes, and/or
- Avoid concentration of inorganic contaminants in leachate


Waste
Heterogeneity
Ponding Water
Impermeable Cover
Preferential Channels
Gas Flow

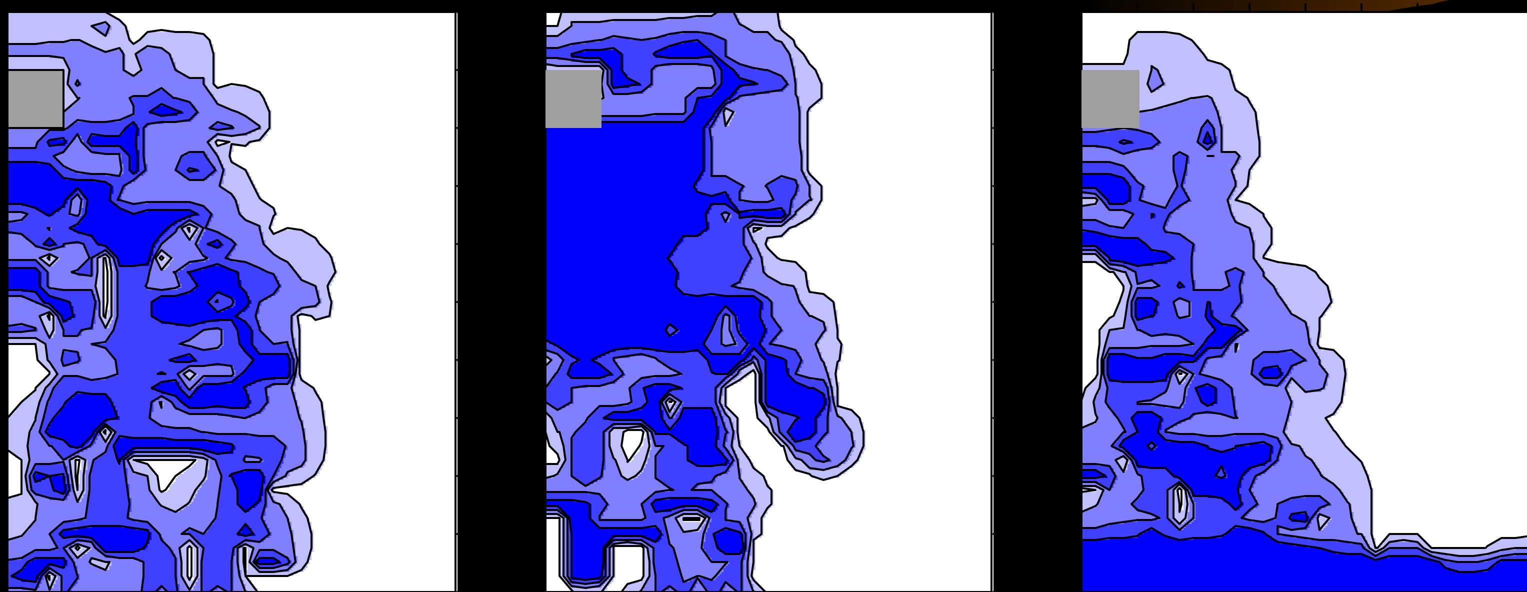
Leachate Applied Intermittently at an average rate of 2 $m^3/m/day$



Waste Permeability = 10^{-3} cm/s

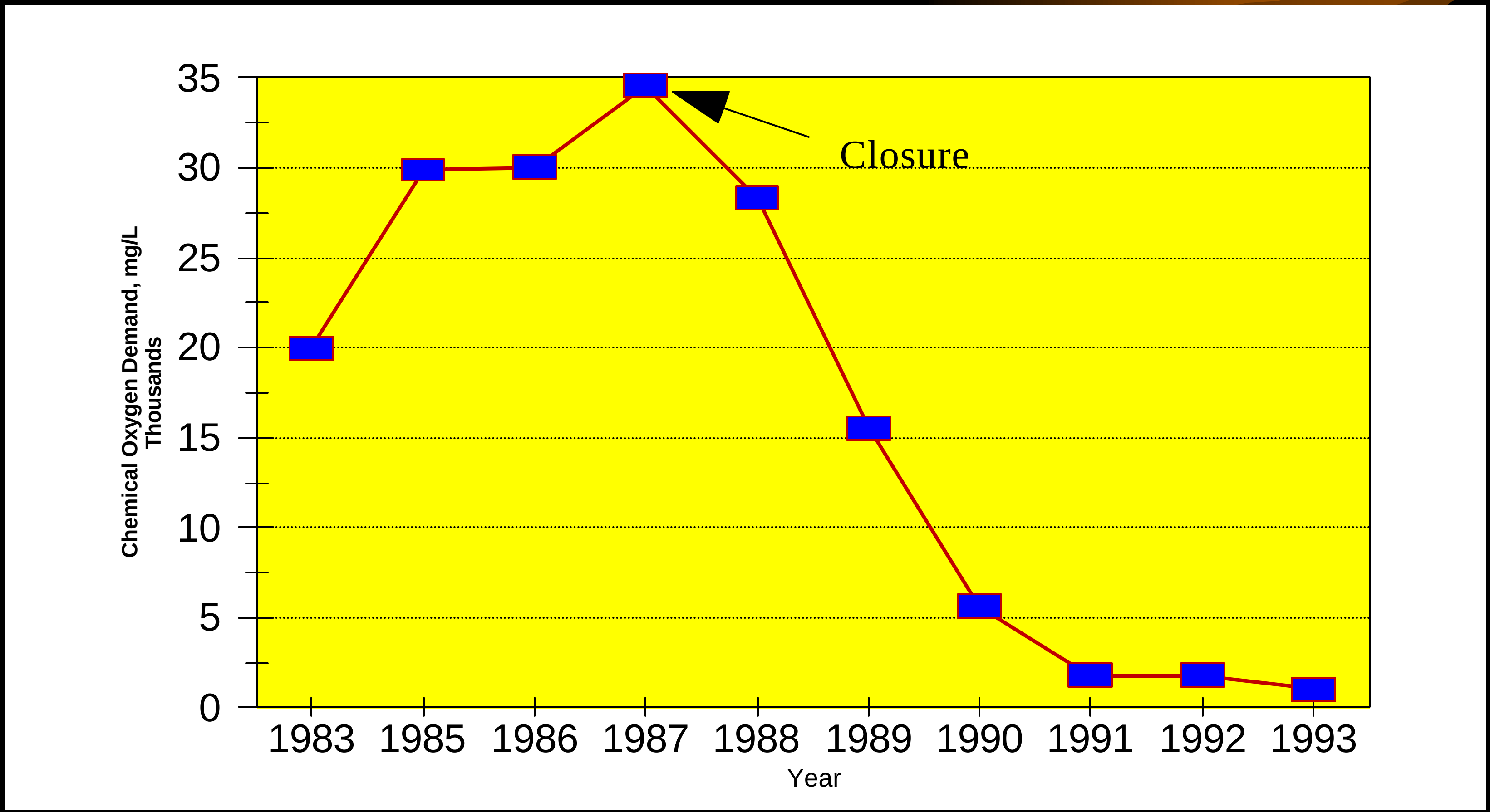
Daily Cover Permeability = 10^{-5} cm/s

Heterogeneities



Landfill Stability

Leachate Quality



Impact of Waste Processing

Recovery of Composted Materials

Aerobic Bioreactor

- Rapid stabilization of waste
- Enhanced settlement
- Evaporation of moisture
- Degradation of organics which are recalcitrant under anaerobic conditions
- Reduction of methane emissions

Research Issues - Aerobic Bioreactor

- How much air is needed?
- How can air be delivered?
- What is the impact on the water balance?
- How are landfill fires prevented?
- What are the economic implications?

Anaerobic Decomposition

$$C_6H_{10}O_5 + H_2O \rightarrow 3CH_4 + 3CO_2$$

Aerobic Decomposition

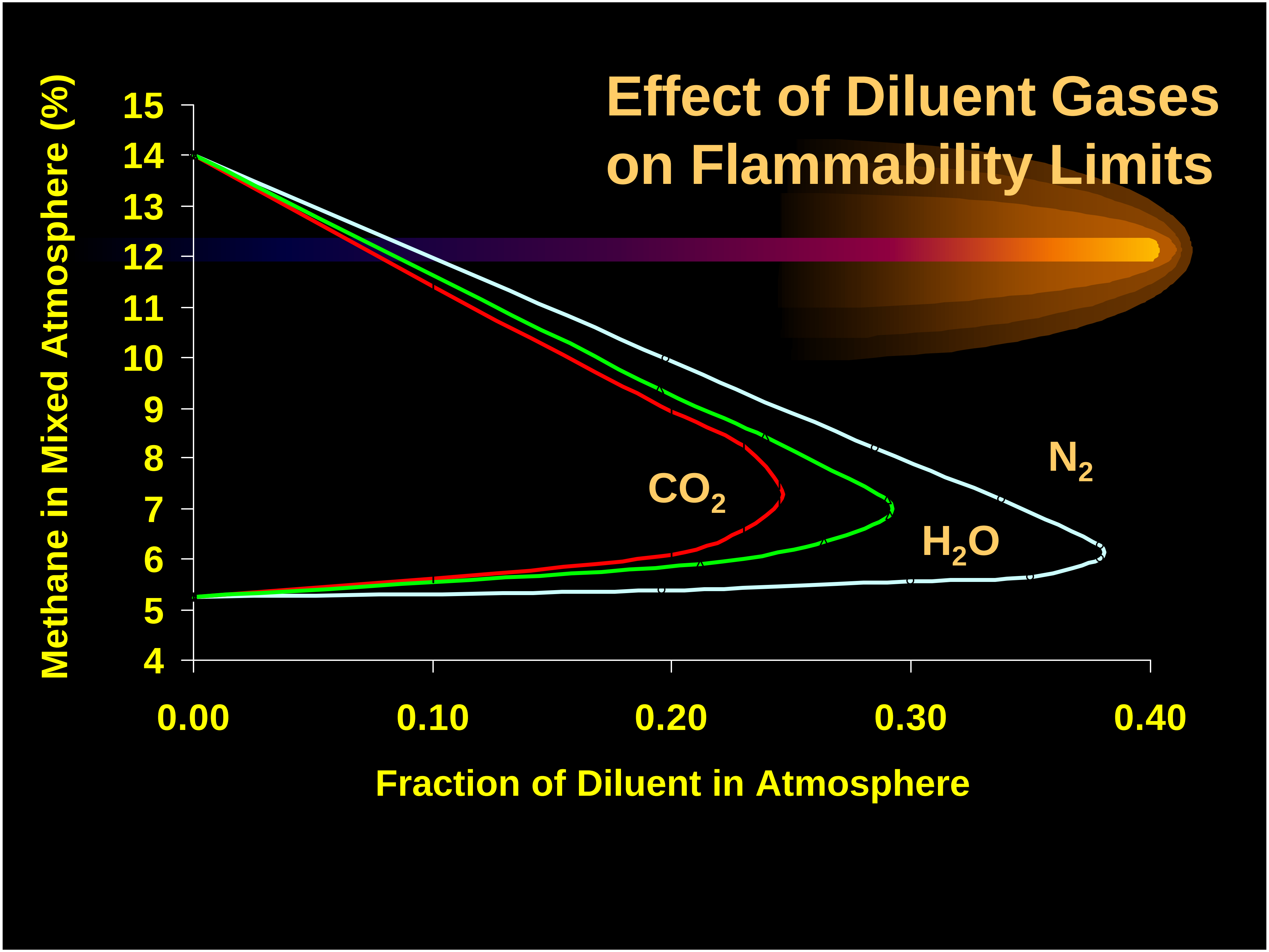
$$C_6H_{10}O_5 + 6O_2 \rightarrow 6CO_2 + 5H_2O$$

Aerobic Landfill

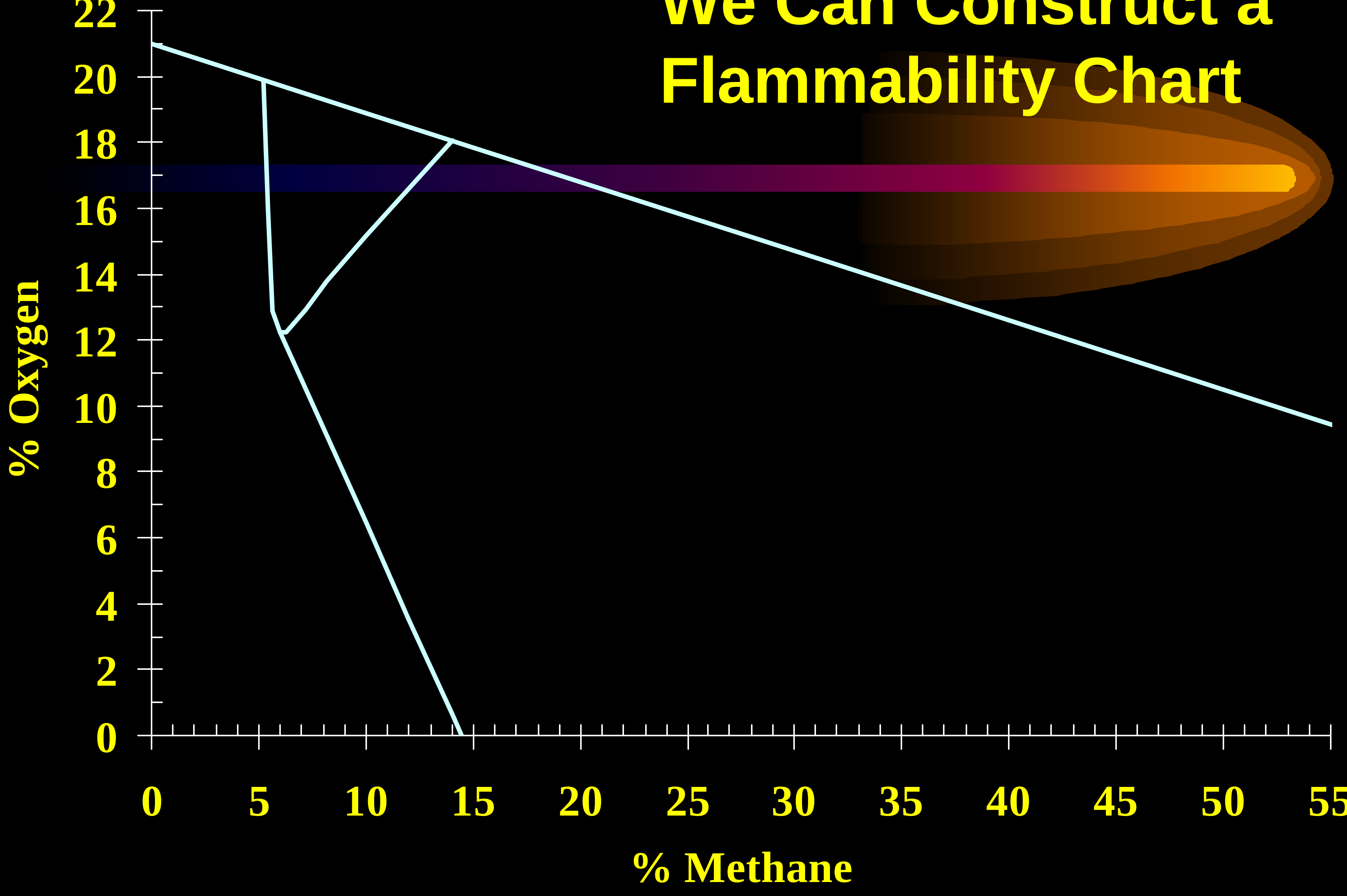
Flammability of Landfill Gas

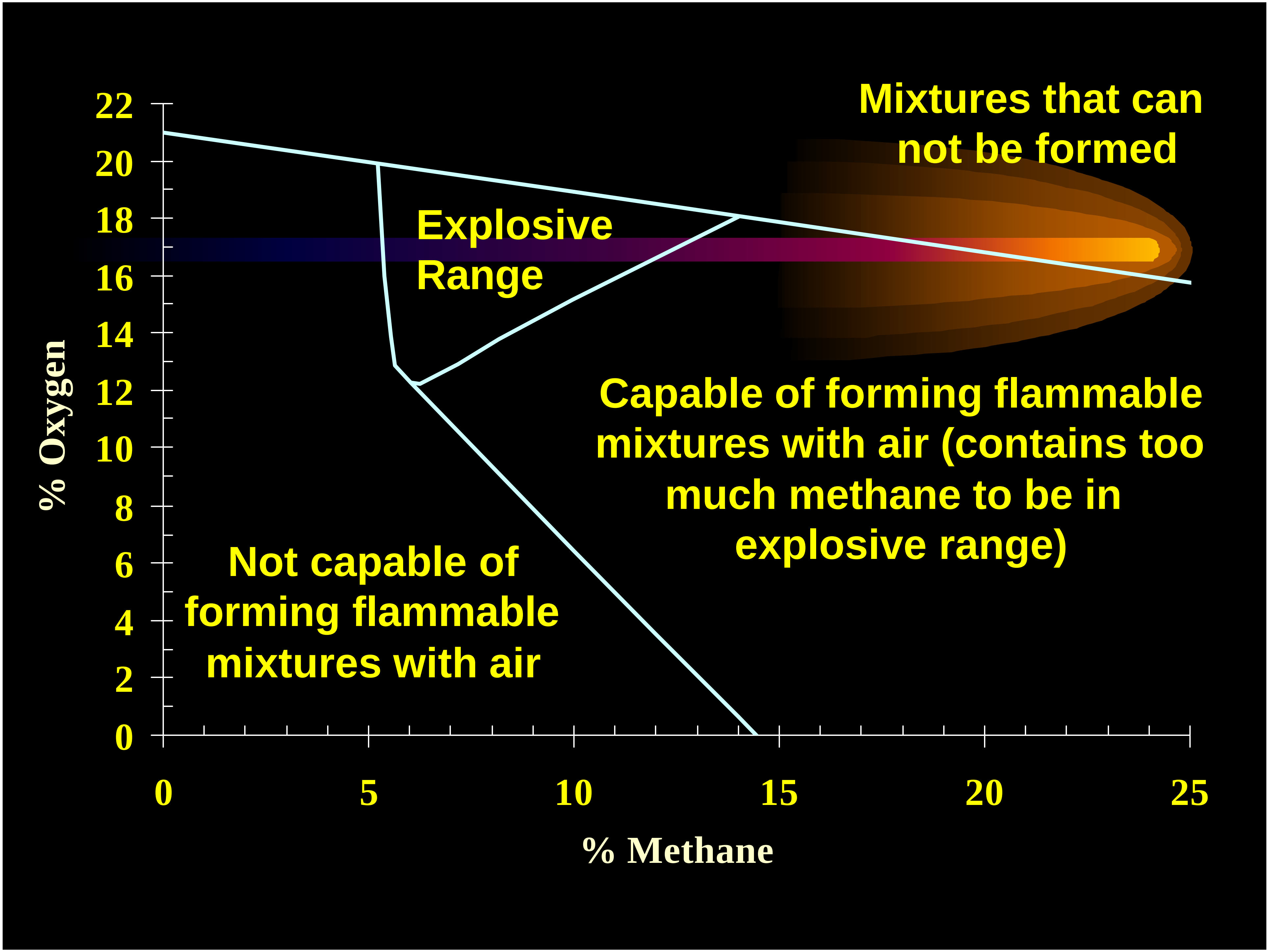
Explosive Range of Methane in Air

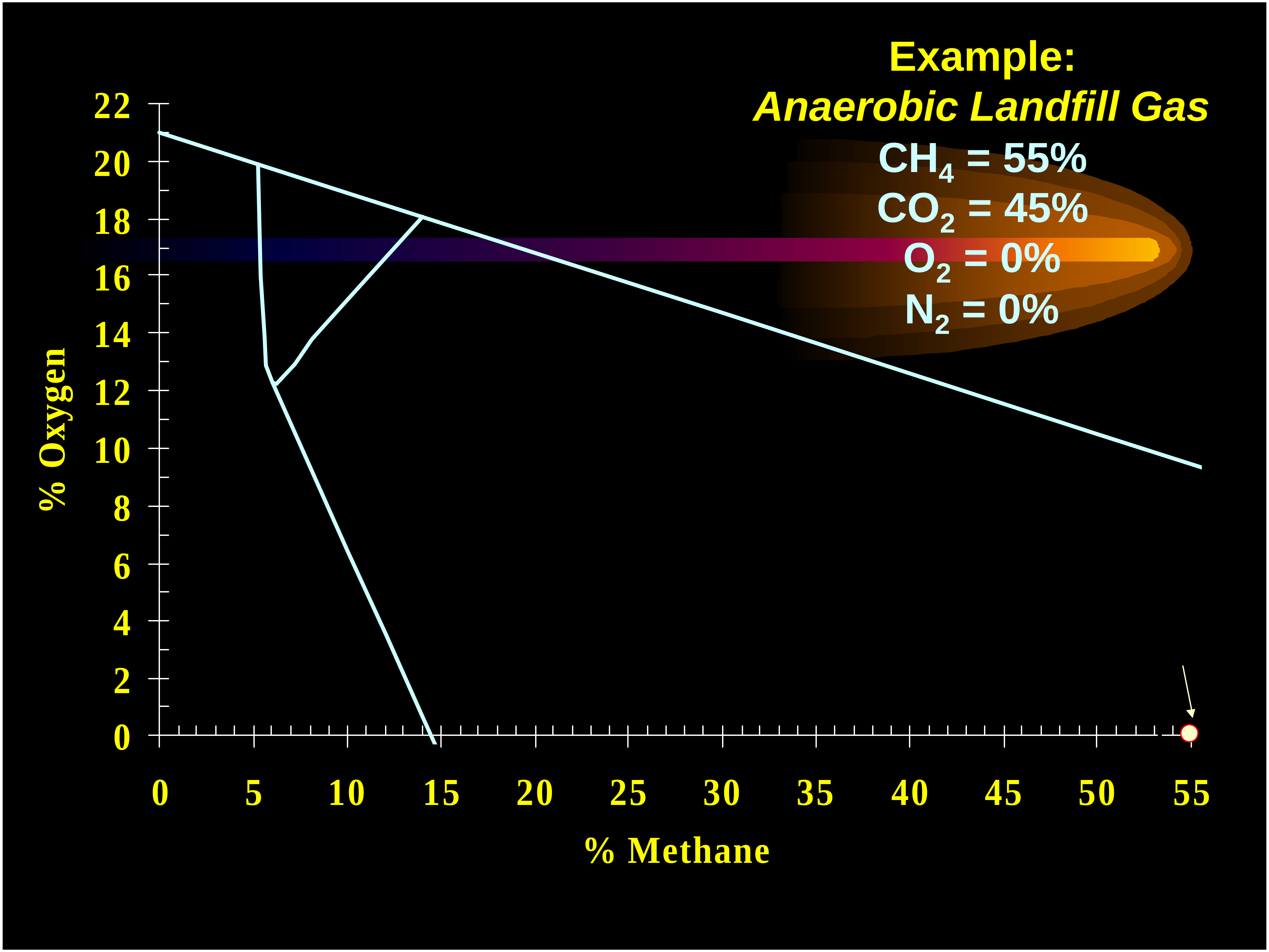
5% to 14/15%

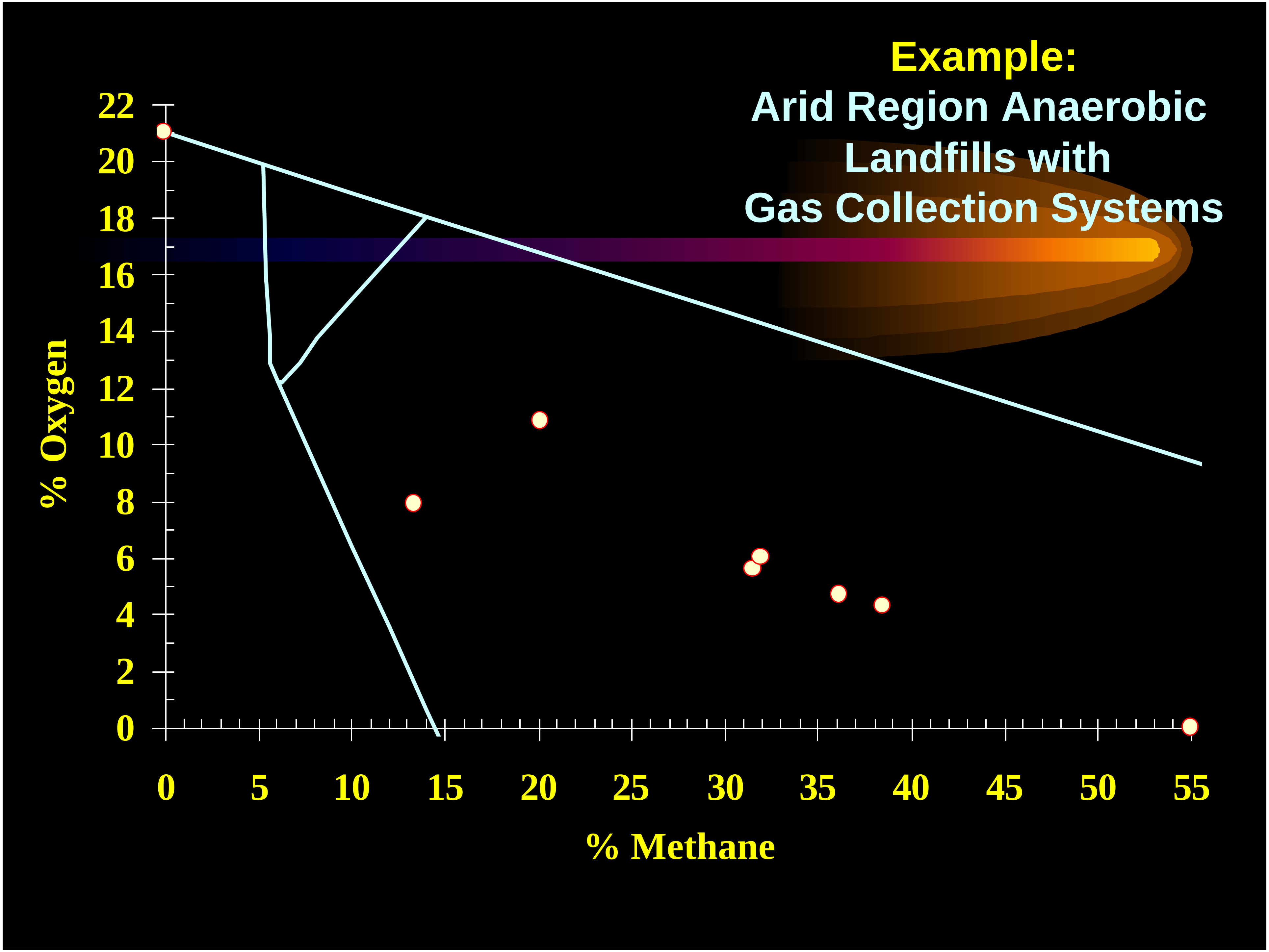

Effect of Diluent Gases on Flammability Limits
Methane in Mixed Atmosphere (%)
15
14
13
12
11
10
9
8
7
6
5
4
0.00
0.10
0.20
0.30
0.40
Fraction of Diluent in Atmosphere
CO_2
H_2O
N_2

We Can Construct a Flammability Chart

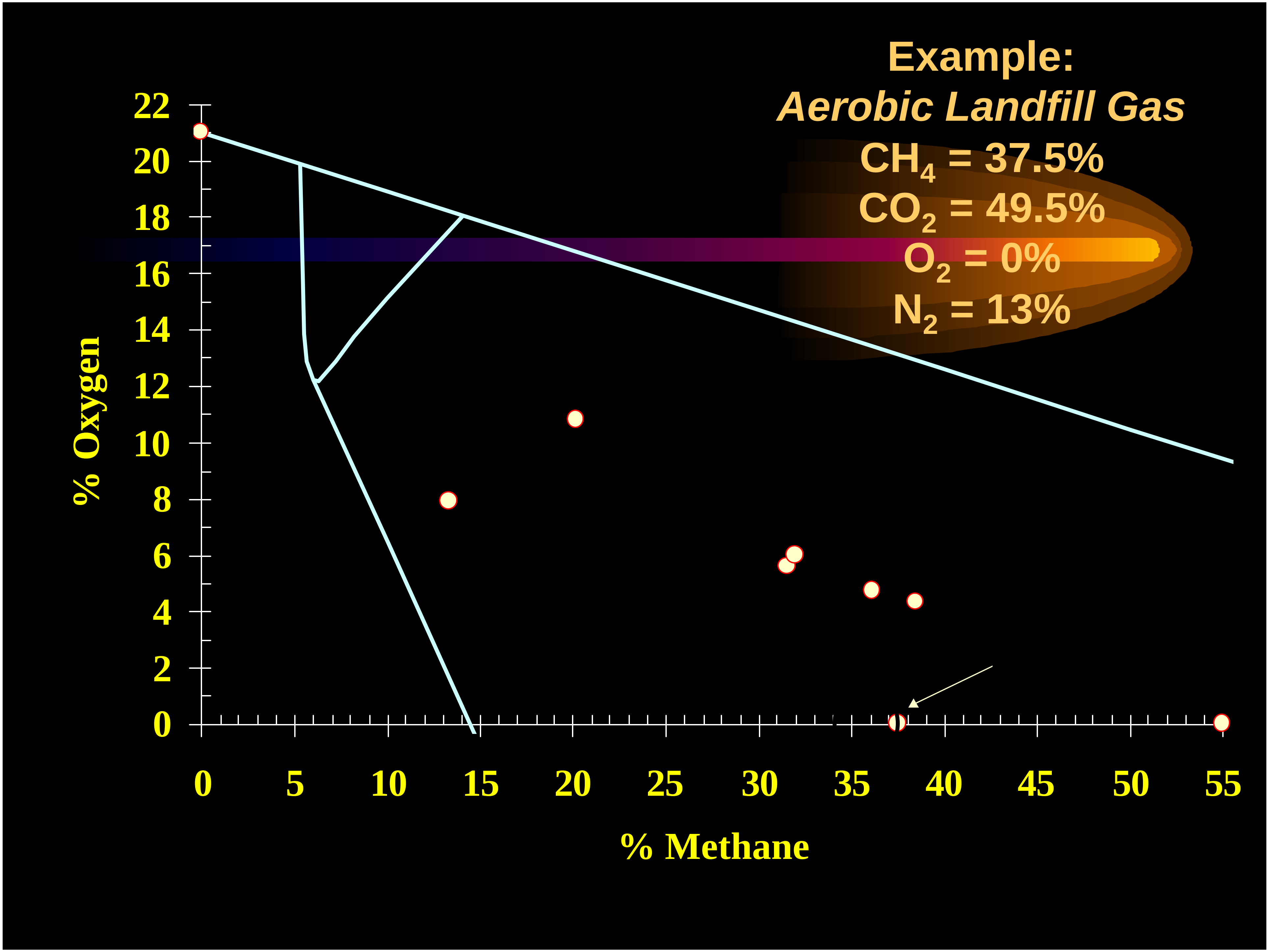



Mixtures that can not be formed
Explosive Range
Capable of forming flammable mixtures with air (contains too much methane to be in explosive range)
Not capable of forming flammable mixtures with air
% Oxygen
22
20
18
16
14
12
10
8
6
4
2
0
0
5
10
15
20
25
% Methane

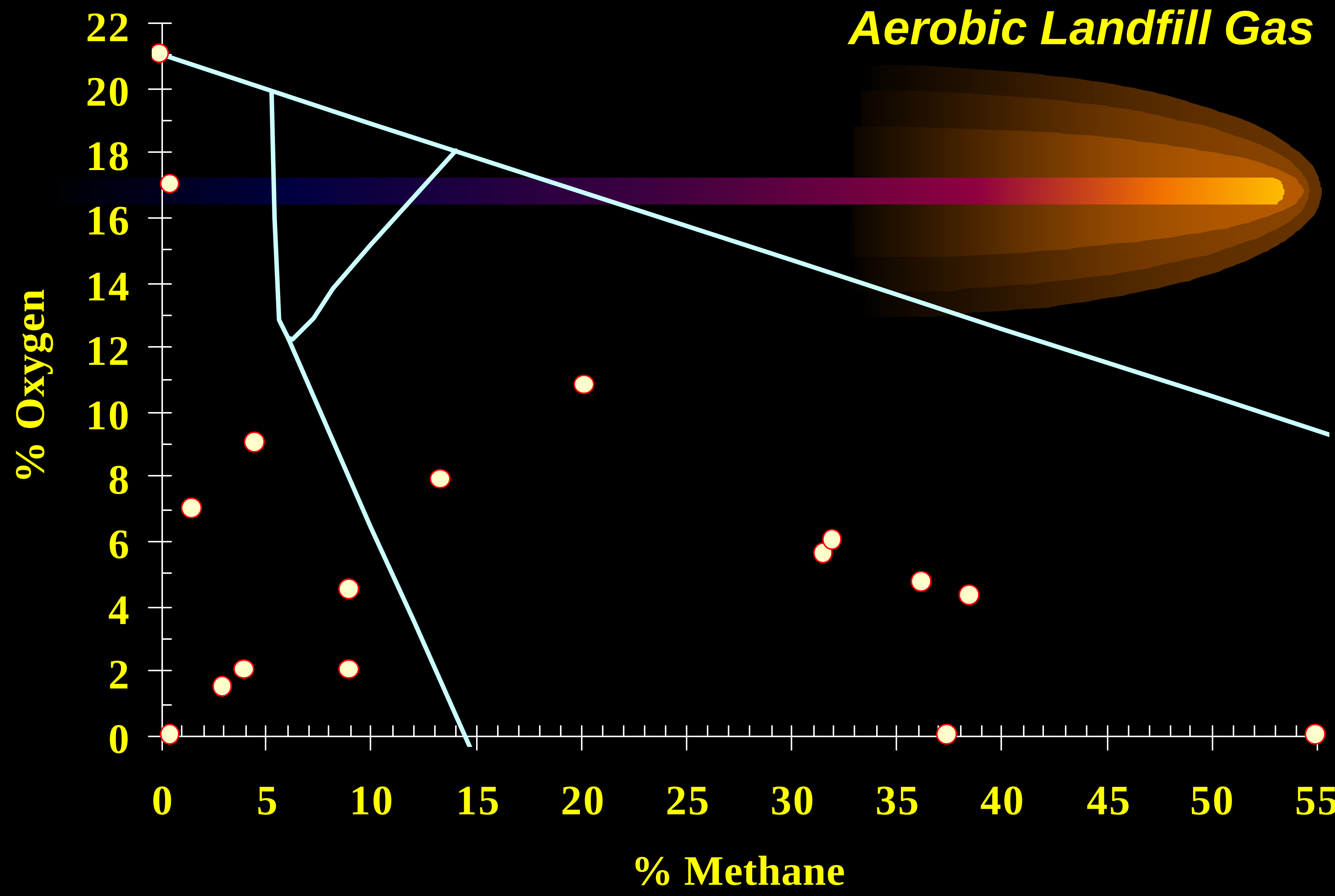

Example:
Anaerobic Landfill Gas
CH4 = 55%
CO2 = 45%
O2 = 0%
N2 = 0%
% Oxygen
% Methane
22
20
18
16
14
12
10
8
6
4
2
0
5
10
15
20
25
30
35
40
45
50
55



Example:
Arid Region Anaerobic
Landfills with
Gas Collection Systems
% Oxygen
22
20
18
16
14
12
10
8
6
4
2
0
0
5
10
15
20
25
30
35
40
45
50
55
% Methane


Example:
Aerobic Landfill Gas
CH4 = 37.5%
CO2 = 49.5%
O2 = 0%
N2 = 13%
% Oxygen
22
20
18
16
14
12
10
8
6
4
2
0
0
5
10
15
20
25
30
35
40
45
50
55
% Methane

Example:
Aerobic Landfill Gas



Economic Impacts

Benefits

- Enhanced gas production
- Recovered space
- Reduced env. impact
- Reducted post-closure care

Costs

- Capital costs
- Operating costs