THE BIOREACTOR LANDFILL PARADIGM

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OUTLINE OF PRESENTATION

- **Fundamental Definitions**
- **From the Way We Were**
- **Today and Beyond**

FUNDAMENTAL DEFINITIONS

- **Reactor**
  - **a containment structure in which reactions are initiated and controlled to optimize a desired outcome**
- **Bioreactor**
  - **a biologically-mediated reactor**
- **Bioreactor Landfill**
  - **a bioreactor where the containment structure is a landfill or a portion of a landfill**

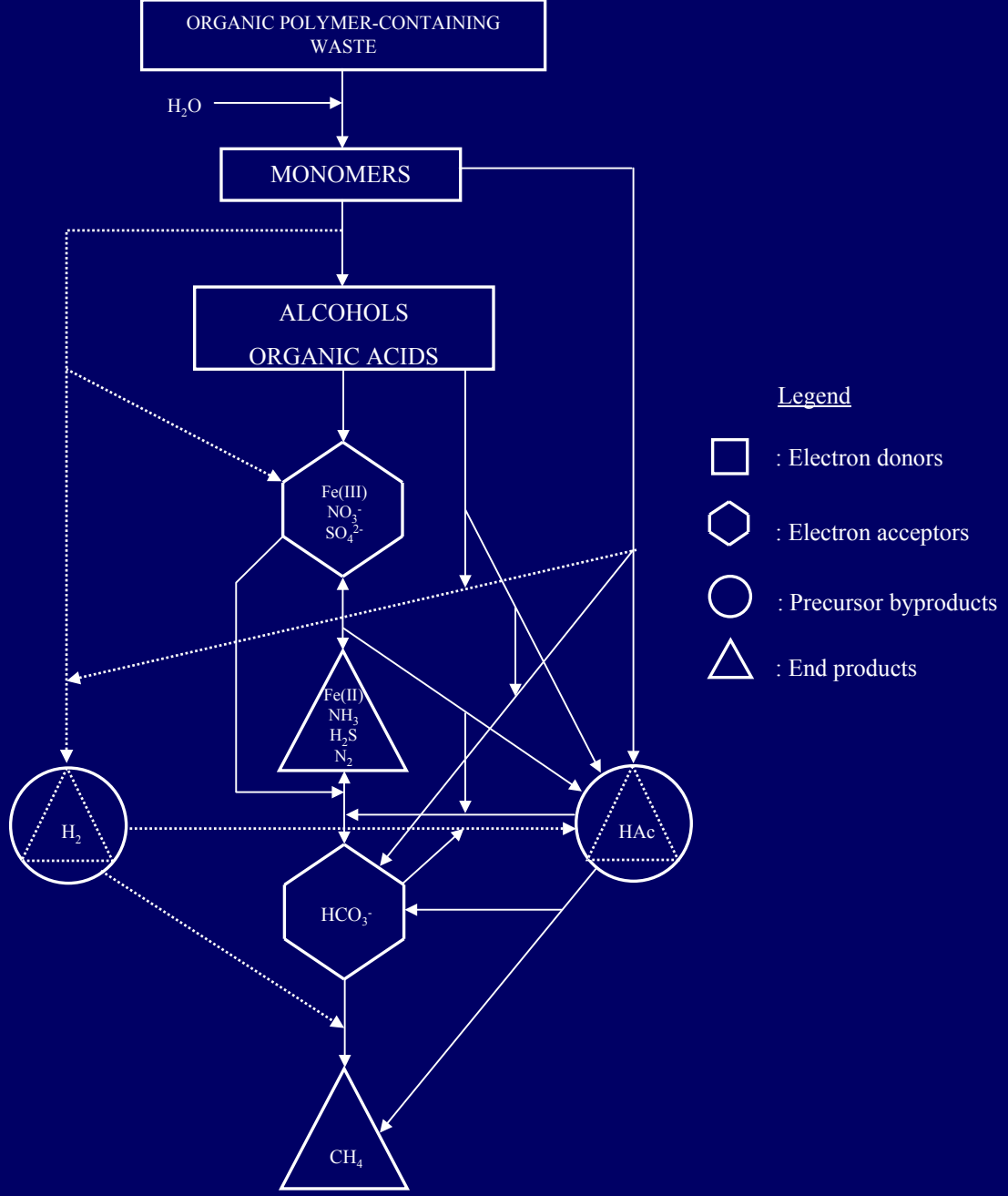
FUNDAMENTAL DEFINITIONS (Cont'd.)

- **Paradigm**
  - **an example, model or archetype of which all things of the same type are representatives or copies**
- **Bioreactor Landfill Paradigm**
  - **a landfill archetype with leachate recirculation to accelerate and/or enhance biodegradation and stabilization**

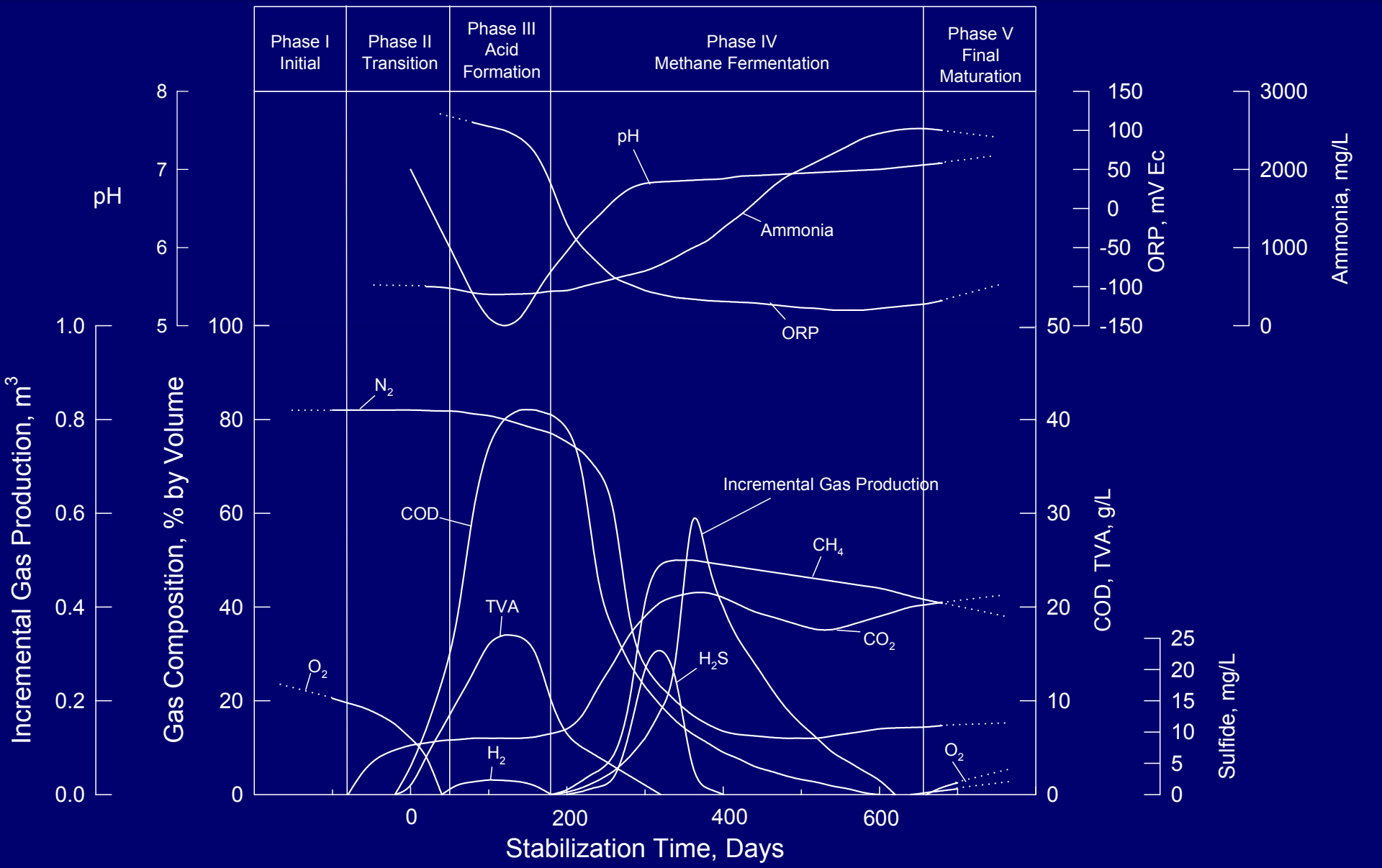
FROM THE WAY WE WERE

- **Past Landfill Practices**
  - **uncontrolled dumping/impacts**
- **The Emergence of a Paradigm**
  - **leachate and gas management**
  - **engineered landfill systems**
- **Scientific and Technical Renaissance**
  - **translation of fundamental scientific principles into rationale design, operation and control**
- **Regulatory Impacts**
  - **away from command and control**


SOLID WASTE R+D LANDFILL
J.GLISSON CHMN
AUGUST 24-28 1970
ENGINEERING FOUNDATION
RESEARCH CONFERENCES
HENNIKER ACADEMY
HENNIKER MASS. 03242
1954



Waste Conversion Sequences in Landfill Bioreactor Systems



Stabilization characteristics within a bioreactor landfill unit

Redox Half-reaction Responsible during Anaerobic Stabilization in Bioreactor Landfills

Oxidations (Electron Donating Reactions)[a]		ΔG, kJ
Caproate ↔ Propionate	$CH_3(CH_2)_4COO^- + 2H_2O \leftrightarrow 2CH_3CH_2COO^- + H^+ + 2H_2$	+48.3
Caproate ↔ Acetate	$CH_3(CH_2)_4COO^- + 4H_2O \leftrightarrow 3CH_3COO^- + 2H^+ + 4H_2$	+96.7
Caproate ↔ Butyrate + Acetate	$CH_3(CH_2)_4COO^- + 2H_2O \leftrightarrow CH_3(CH_2)_2COO^- + CH_3COO^- + H^+ + 2H_2$	+48.4
Propionate ↔ Acetate	$CH_3CH_2COO^- + 3H_2O \leftrightarrow CH_3COO^- + HCO_3^- + H^+ + 3H_2$	+76.1
Butyrate ↔ Acetate	$CH_3CH_2CH_2COO^- + 2H_2O \leftrightarrow 2CH_3COO^- + H^+ + 2H_2$	+48.1
Ethanol ↔ Acetate	$CH_3CH_2OH + H_2O \leftrightarrow CH_3COO^- + H^+ + 2H_2$	+9.6
Lactate ↔ Acetate	$CH_3CHOHCOO^- + 2H_2O \leftrightarrow CH_3COO^- + HCO_3^- + H^+ + 2H_2$	-4.2
Acetate ↔ Methane	$CH_3COO^- + H_2O \leftrightarrow HCO_3^- + CH_4$	-31.0
Reductions (Electron Accepting Reactions)[a]		
HCO_3^- ↔ Acetate	$2HCO_3^- + 4H_2 + H^+ \leftrightarrow CH_3COO^- + 4H_2O$	-104.6
HCO_3^- ↔ Methane	$HCO_3^- + 4H_2 + H^+ \leftrightarrow CH_4 + 3H_2O$	-135.6
Sulfate ↔ Sulfide	$SO_4^{2-} + 4H_2 + H^+ \leftrightarrow HS^- + 4H_2O$	-151.9
	$CH_3COO^- + SO_4^{2-} + H^+ \leftrightarrow 2HCO_3^- + H_2S$	-59.9
Nitrate ↔ Ammonia	$NO_3^- + 4H_2 + 2H^+ \leftrightarrow NH_4^+ + 3H_2O$	-599.6
	$CH_3COO^- + NO_3^- + H^+ + H_2O \leftrightarrow 2HCO_3^- + NH_4^+$	-511.4
Nitrate ↔ Nitrogen Gas	$2NO_3^- + 5H_2 + 2H^+ \leftrightarrow N_2 + 6H_2O$	-1,120.5
Note: [a] pH 7, 1 atm, 1 kg/mol activity, 25°C		

Bioreactor landfill attenuation of representative recalcitrant organic and inorganic constituents*

Constituents	Dominant Attenuation Mechanisms during Landfill Stabilization Phases
Heavy Metals (Cd, Cu, Cr, Fe, Hg, Ni, Pb, Zn)	Conversion to a reduced oxidation state with complex formation and volatilization (Fe, Cr, Hg). Mobilization and salt formation in leachate in the presence of organic (e.g., aromatic hydroxide, carboxylic acid, aromatic amine, humic and fulvic acid) and inorganic (e.g., chloride, sulfate, carbonate) ligands. Formation of sparingly soluble hydroxides (Cr) and sulfates (Cd, Cu, Fe, Hg, Ni, Pb, Zn) after sulfate reduction, and precipitation. Physical sorption and ion exchange within the waste matrix. Filtration and retention within stagnant pools of interstitial water.
Organic Compounds**	
Halogenated Aliphatics (PCE, TCE, DBM)	Volatilization and mobilization in gas and leachate prior to abiotic and biotic reductive dehalogenation under methanogenic, methanotrophic, sulfate reducing and denitrifying conditions.
Chlorinated Benzenes (HCB, TCB, DCB)	Volatilization and sorptive matrix capture prior to partial reductive dechlorination.
Phenolics and Nitroaromatics (DCP, NP, NB)	Mobilization in leachate prior to dechlorination or nitro-group reduction, biodegradation and complexation.
Phthalate Esters (BEHP), Polynuclear Aromatics (NAP), and Pesticides (LIN, DIEL)	Low volatility and mobility in gas and leachate prior to complete or partial biodegradation.

* References: Pohland et al. (2002).

** Perchloroethene (PCE), Trichloroethene (TCE), Dibromomethane (DBM), Hexachlorobenzene (HCB), Trichlorobenzene (TCB), Dichlorobenzene (DCB), Dichlorophenol (DCP), Nitrophenol (NP), Nitrobenzene (NB), Bis (2-ethylhexyl)phthalate (BEHP), Naphthalene (NAP), Lindane (LIN), Diedrin (DIEL); includes daughter products.

TODAY AND BEYOND

- **Needs Assessment and Resolution**
  - **Scientific and technical inquiry/discovery/application**
- **Rational Management and Oversight**
  - **Checks and balances**
- **Stakeholder Harmonization**
  - **Perspective and participation**
- **Sustainability**
  - **Goals achievement**

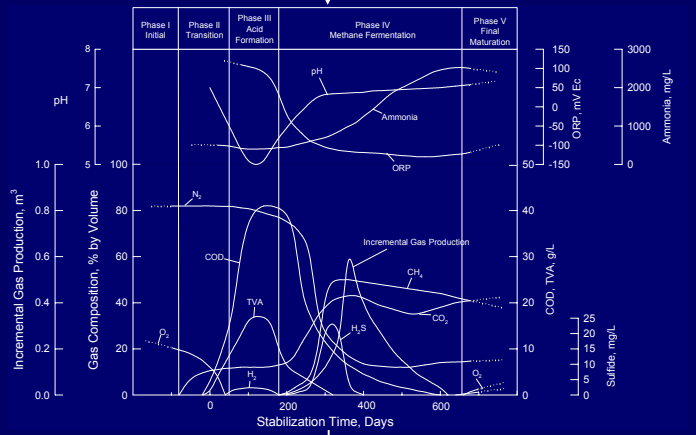
DIRECT USE

PIPELINE QUALITY

GAS TREATMENT

ON-LINE FLARING

LANDFILL



IN SITU VS. EXTERNAL TREATMENT

LEACHATE RECYCLE

EXTERNAL TREATMENT

BIOLOGICAL TREATMENT

ACTIVATED SLUDGE
AERATED LAGOON
STABILIZATION POND
TRICKLING FILTER
ANAEROBIC FILTER
ANAEROBIC CONTACT
NITRIFICATION
DENITRIFICATION

COMBINED TREATMENT

PHYSICAL/CHEMICAL TREATMENT

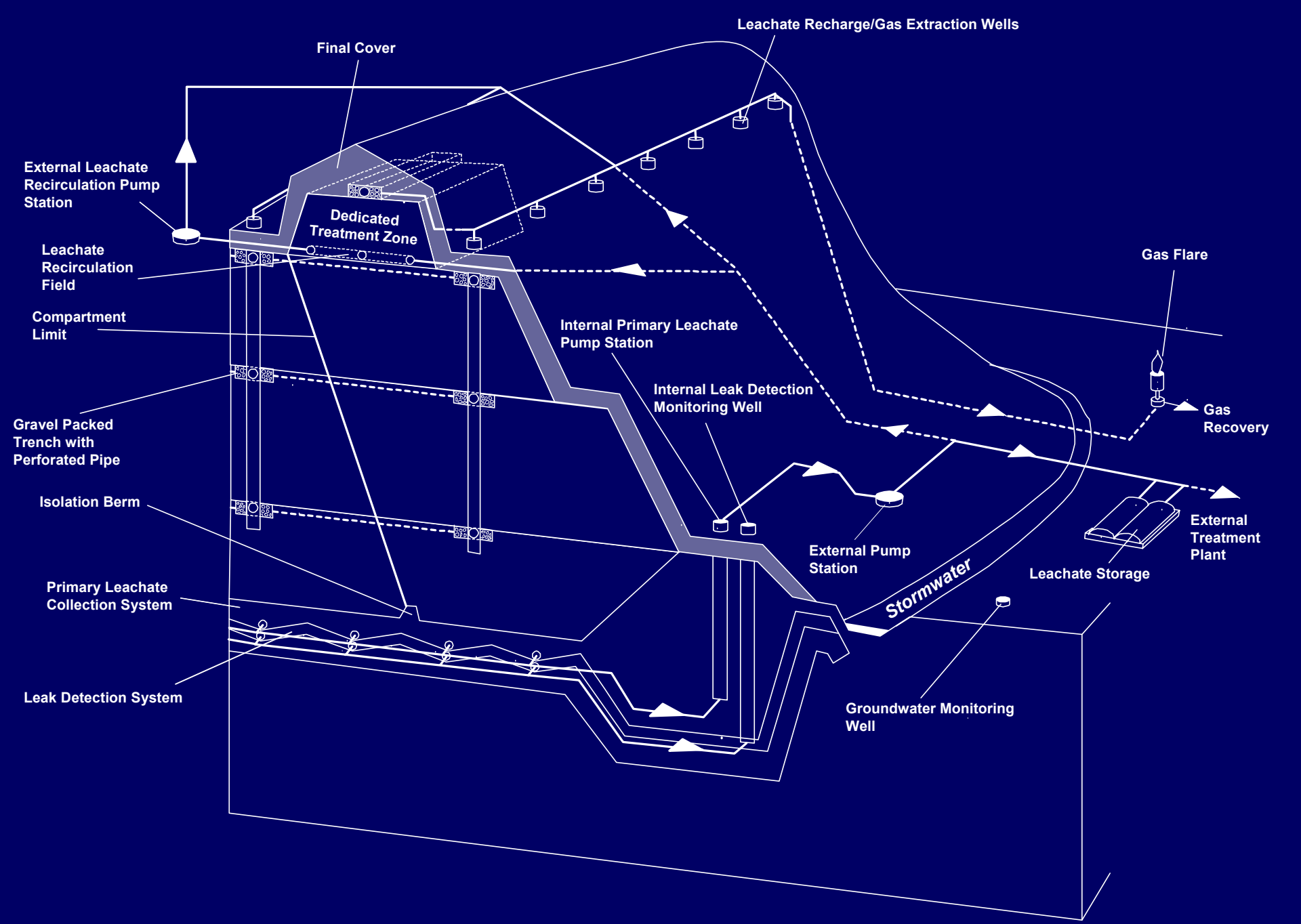
PRECIPITATION/COAGULATION
CHEMICAL OXIDATION/REDUCTION
ADSORPTION
ION EXCHANGE
REVERSE OSMOSIS
DISINFECTION

POTW

DISCHARGE OPTION

LAND APPLICATION

Bioreactor Landfill with Leachate and Gas Treatment Options



Operational features of a bioreactor landfill