# Anaerobic Digestion Applications for Municipal Solid Waste: Fundamentals, Designs, and Current Projects

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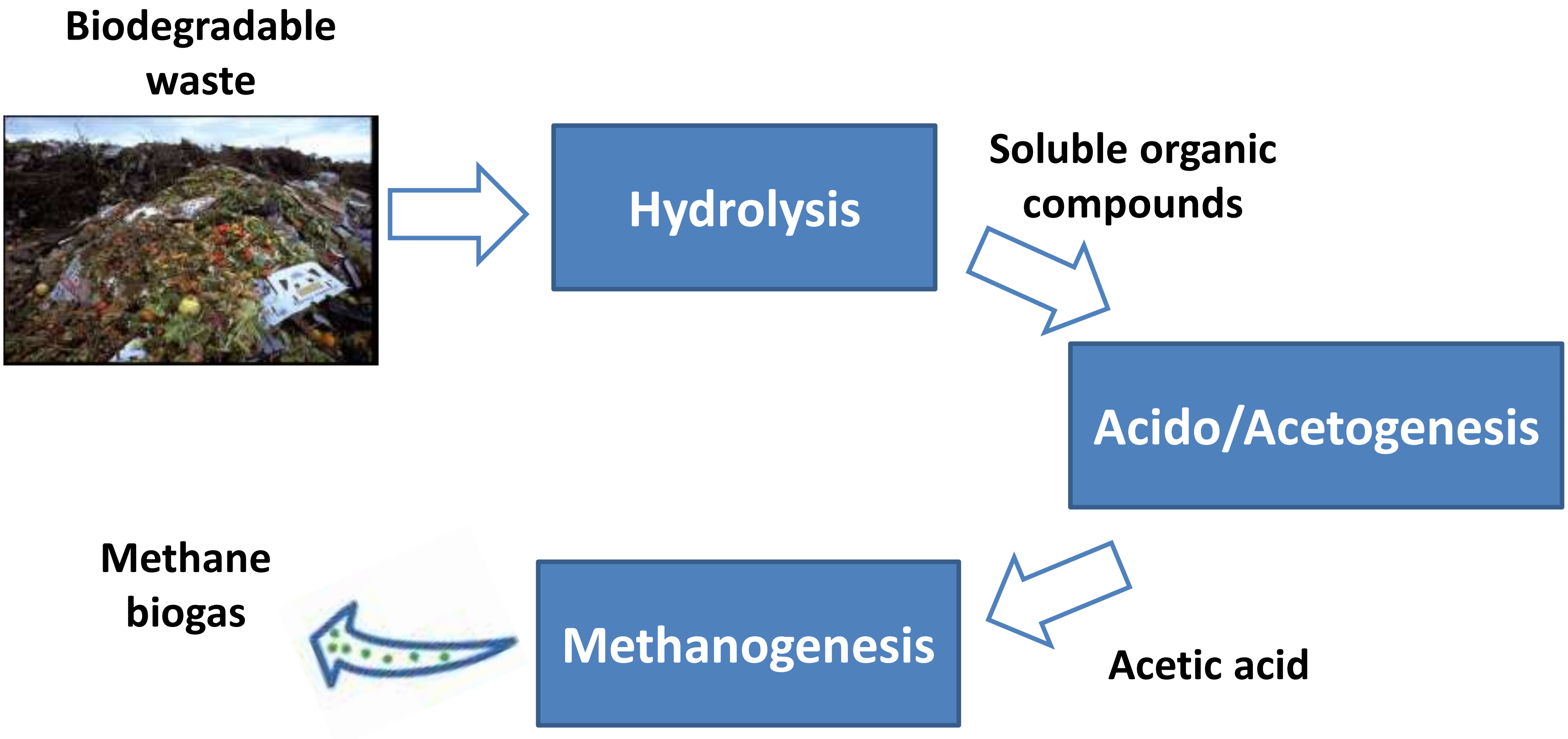
# Outline of Presentation

1. Overview of anaerobic digestion microbiology
2. Anaerobic digestion technologies used for treatment of municipal solid waste including:
   a) Low-solids technologies
   b) High-solids technologies
3. Advantages and disadvantages of available technologies
4. History and current projects of full-scale AD of MSW including:
   a) Demonstration plants and commercial digesters in North America
   b) Commercial digesters in Europe, Asia and others

# Overview of Anaerobic Digestion Microbiology

- Anaerobic Digestion (AD): a bacterial fermentation process that occurs in the absence of oxygen and produces mainly methane and carbon dioxide.
  - Requires a consortium of microorganisms.
  - Optimum conditions must be provided for microbial activity:
    - near-neutral pH,
    - optimum carbon to nitrogen ratios,
    - nutrients,
    - appropriate temperature (30-40°C or 50-60°C),
    - lack of inhibitors.

# AD Process Schematic



# Categories of AD Systems Used for Treatment of MSW

**Low-solids (Wet, < 15% solids)** **OR** **High-solids (Dry, > 20% solids) ?**

↓

**Batch OR Continuous?**

↓

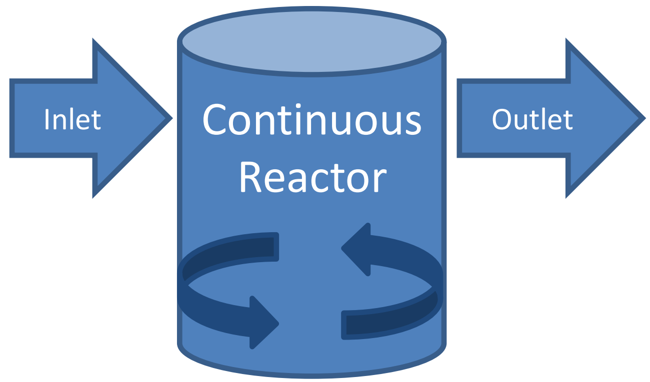
**Single-stage OR Multi-stage?**

- All systems can be mesophilic (operated at 35°C) or thermophilic (operated at 55°C).
- Optimum technology depends on waste composition (e.g., solids content), co-product markets, and other case-specific variables.

# Categories of AD Systems

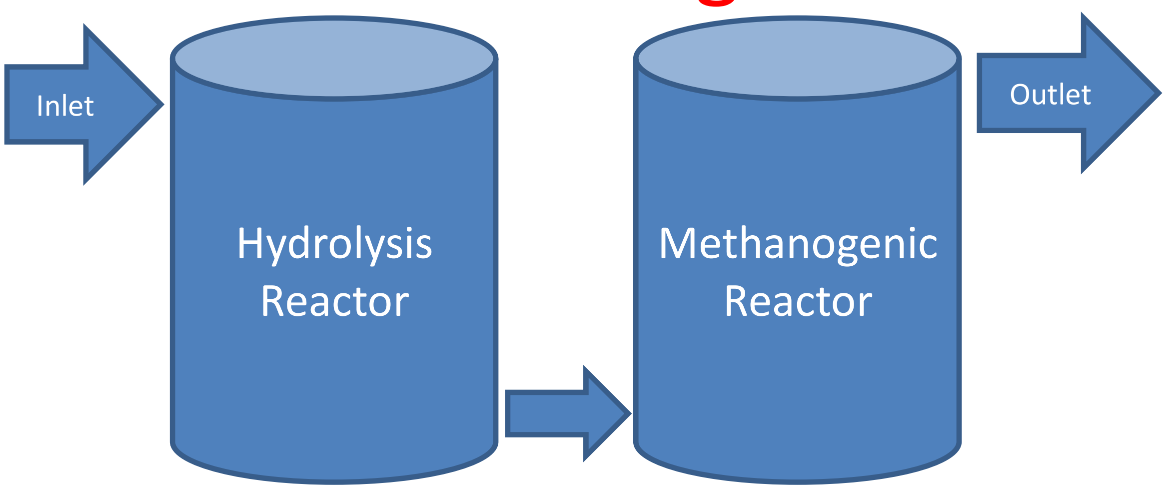
## Single-stage


- Waste added at beginning of cycle.
- Digestion stages occur sequentially.




- Waste added continuously or semi-continuously.

## Multi-stage



# Batch Digesters

- Advantages
  - Simple to build, low capital investment
  - Low water input
  - Could be used to separate other useful products (organic acids)
  - Can also be used for hydrolysis stage in multi-stage processes
- Disadvantages (when used for single-stage processes)
  - Uneven biogas production
    - Lag phase
  - Lack of stability
  - Typically larger footprint of continuous, dry digestion systems
    - Footprint is a function of reactor height and retention time selected

# Low-solids Single-stage

- Best for pulpable slurries (wastewater sludge, manure, pulped foodwaste, co-digestion of wastewater sludge and food waste).
- Feedstock stream must contain <u><15% total solids</u>.
  - MSW requires dilution.
- Organic loading rates typically of 0.033-0.066 lbs VS/gal/day.

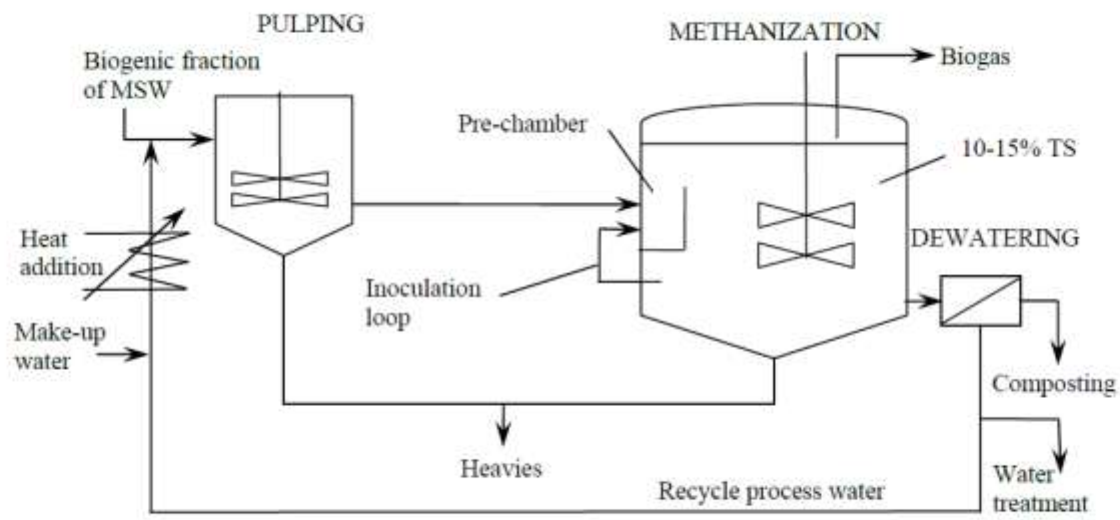



**Figure 10. Schematics of the Waasa one-stage digestion process [45].**

**BIMA**

**Figure from Rapport et al., 2008**

# Low-solids Single-stage

- Advantages
  - Simple to design and operate as compared to multi-stage processes.
  - Less expensive than multi-stage technologies.
- Disadvantages
  - Require low organic loading rate (OLR) because methanogens can easily be disrupted.
  - Longer contact times required.
  - MSW slurries can separate and a scum layer can form that disrupts microbial degradation and clog pipes and pumps.
    - Pretreatment to remove inert solids and homogenize waste required
  - Waste dilution with process water can lead to build up of inhibitors.
  - If toxic compounds are present in MSW they can readily diffuse throughout the reactor and shock microorganisms, including sensitive methanogens.

# Low-solids Multi-stage

- Two (or more stages) separate hydrolysis/fermentation form methanogenesis
  - Stages may be optimized independently
  - More stable than single-stage AD

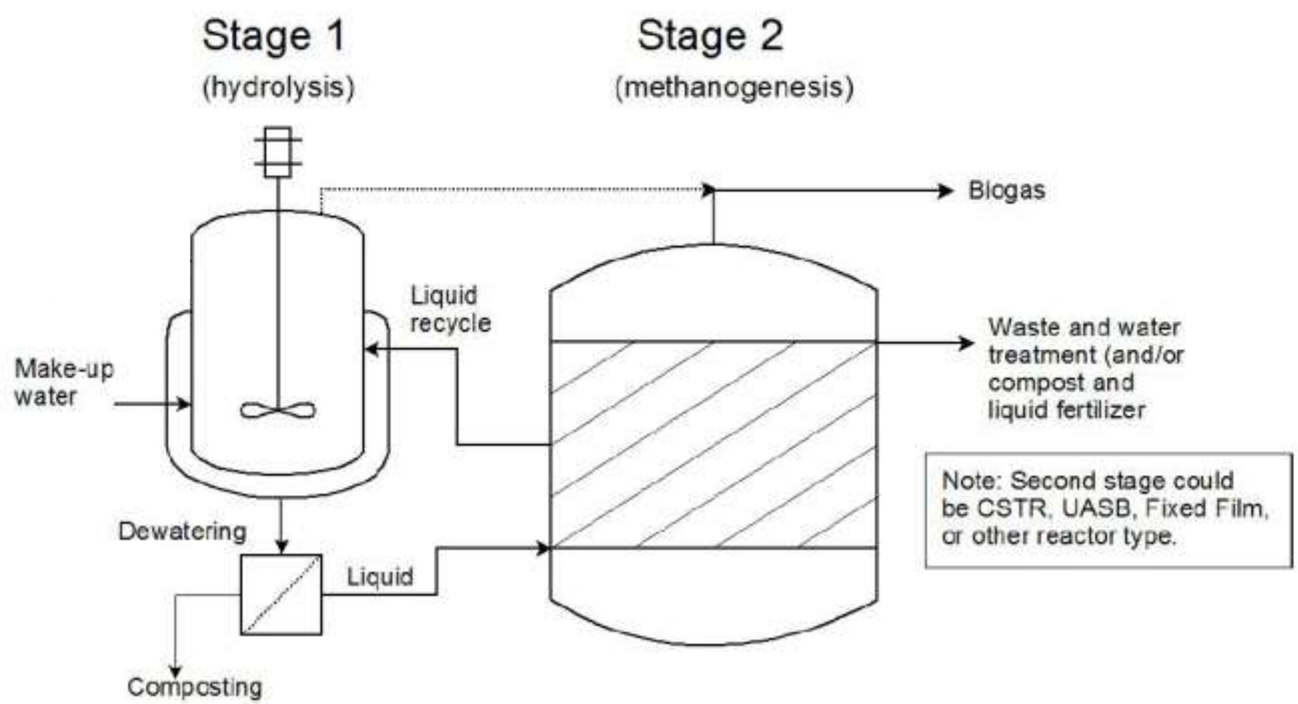



**Figure from Rapport et al., 2008**

# Low-solids Multi-stage

- Advantages
  - Each type of microorganism has different optimal conditions, can optimize processes separately
    - Fermenters prefer lower pH
    - Methanogens prefer 7-8.5
      - Dilute to raise pH prior to methanogenesis
  - Can incorporate high-rate methanogenesis technologies
    - Up-flow anaerobic sludge blankets
    - Fixed-film reactors
  - Higher OLR
  - Higher methane production rates
- Disadvantages
  - Higher capital costs

# High-solids Single-stage

- Popular for application to MSW in Europe.
- Feedstock stream can contain >20% total solids (typically 20-40%).
- Different pre-treatment & transfer equipment required due to high-solids content: conveyor belts and pumps designed for highly viscous streams.
- Typically plug flow systems (horizontal or vertical).
- Incoming waste must be inoculated to avoid pockets of acid buildup.

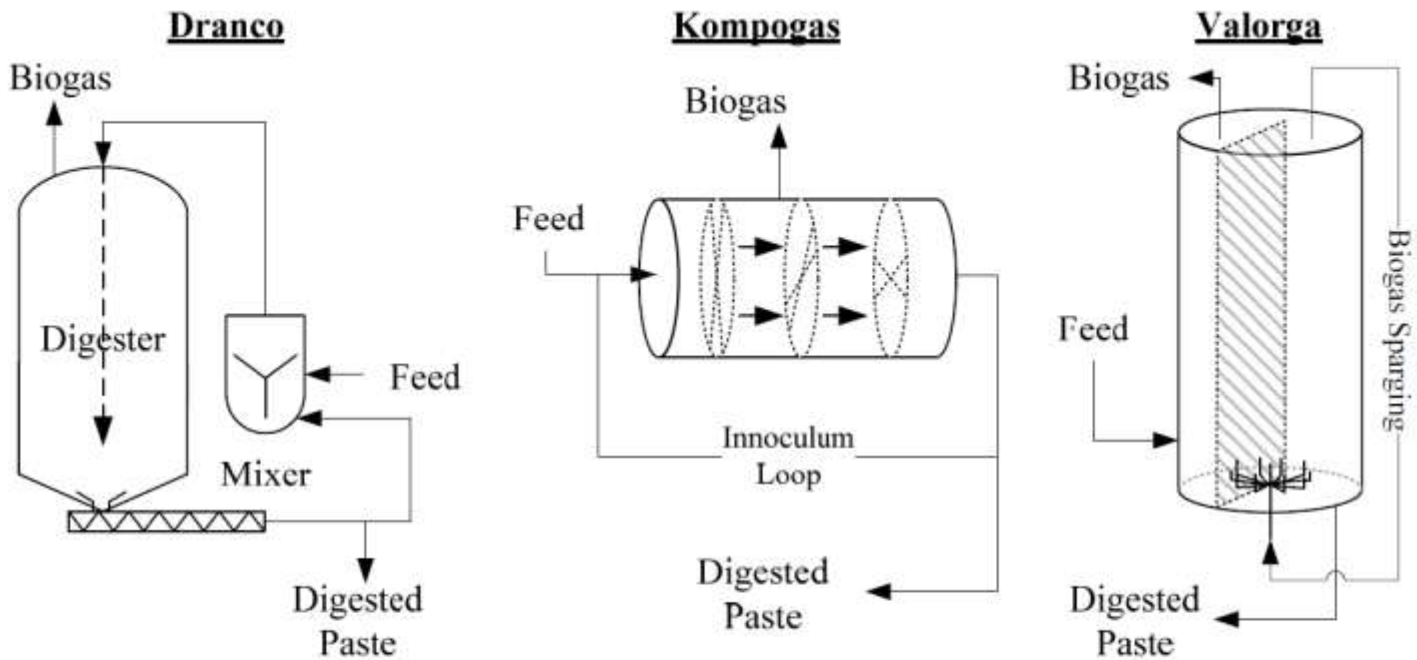



Figure 12). All three systems operate as plug-flow digesters.

**Figure from Rapport et al., 2008**

# Sizing

| Reactor Type | Retention Time (days) |
|---|---|
| Plug Flow | 20 - 50 |
| Complete Mix | 10 - 20 |
| High Rate (e.g., Fixed Film) | 2 - 10 |

- Selection of Retention Time ($\theta$) dependent on waste

# Kompogas process

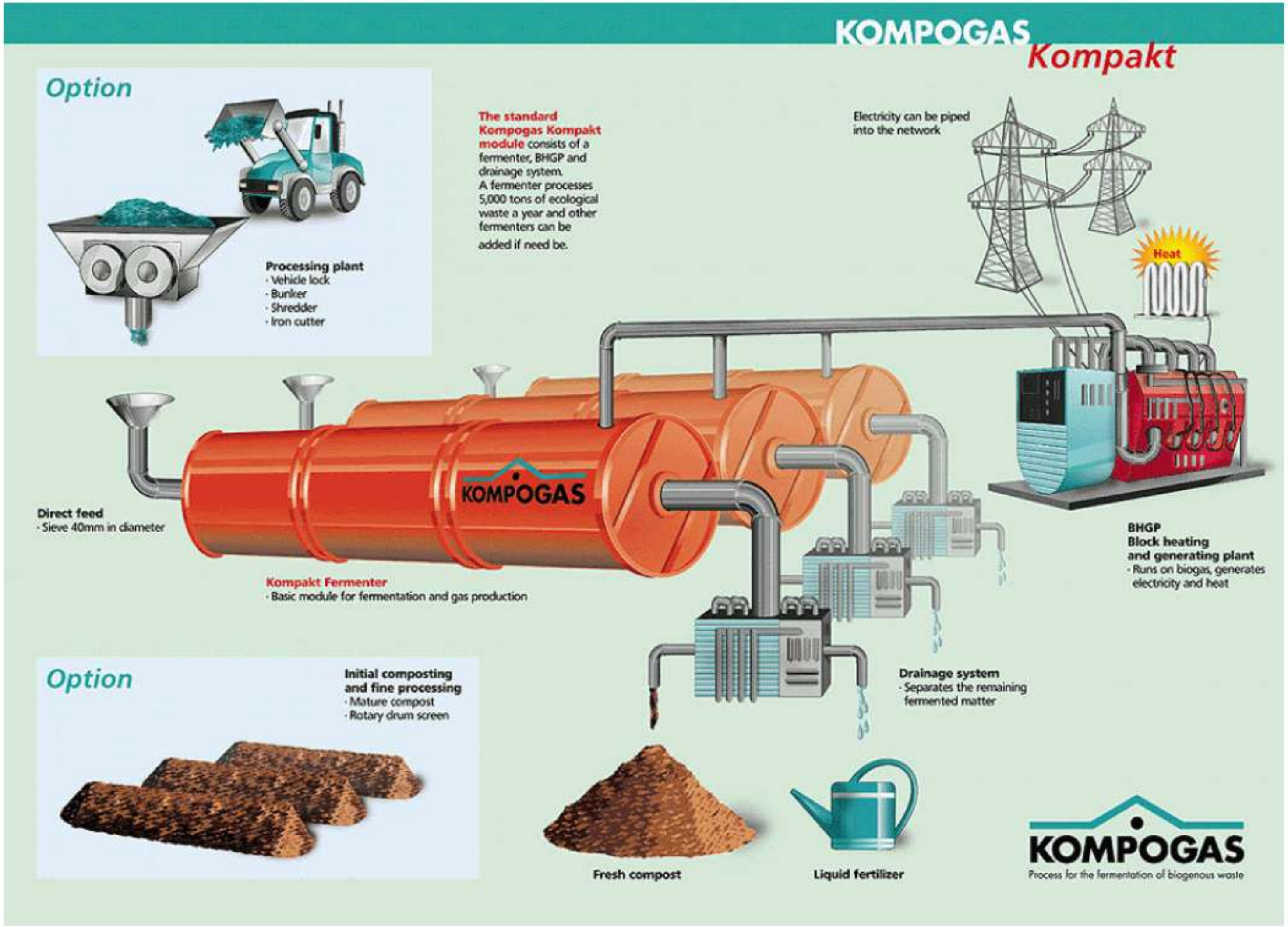



**Figure 15. Overview of the Kompogas process**
From the company website, accessed September 2007.

# BIOFerm System

- Solids > 40%

**The BIOFerm™ System:**

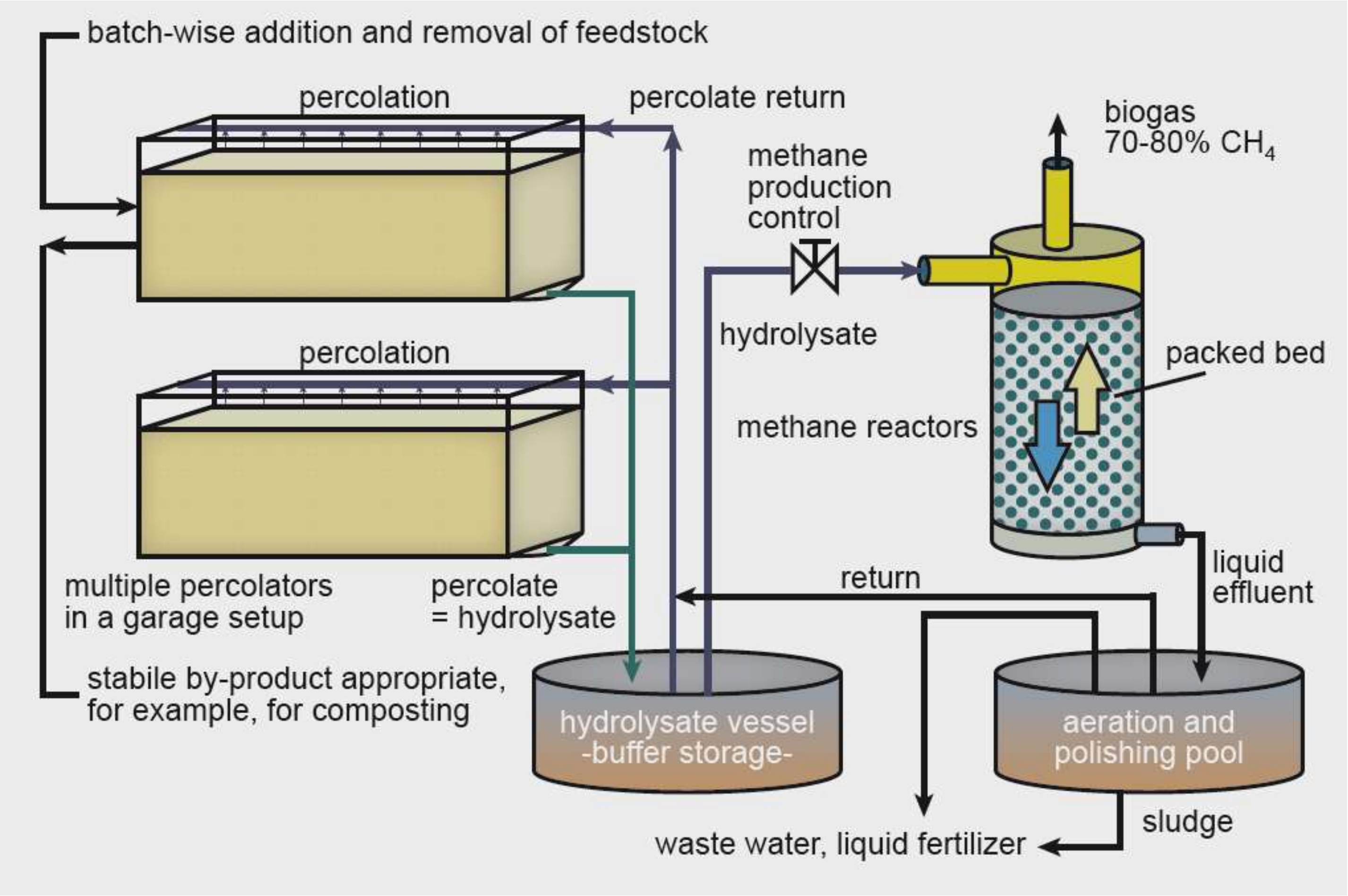

1. Biomass Storage
2. Mixing Platform
3. Fermentation Chamber
4. Flexible Gas Storage
5. Biogas Boiler
6. CHP
7. To District Heating
8. Electric Grid Connection

# High-solids Single-stage

- Advantages
  - Biogas generation rates comparable to or greater than wet systems.
  - Dilution water often not required.
  - High OLR: ~0.1 lbs/gal/d (Dranco), depends on VS content.
  - Lower diffusion rate prevents toxic compounds from impacting microbes throughout reactor → systems are more robust.
  - Minimal pretreatment requirements → removal of large materials (> 2 in).
    - Systems more tolerant of contaminants (rocks, glass, plastics, metals, wood, etc.). Contaminants can be removed after digestion.
- Disadvantages
  - Handling, mixing and pumping of waste are challenging.
    - Heavy duty pumps, augers and conveyors are required to handle waste, which can be expensive.
  - Higher capital costs.
  - Impacted by general disadvantages of single-stage systems.

# High-solids Multi-stage

- Increasingly popular for application to MSW.
- Feedstock stream can contain >20% total solids (typically 20-40%).



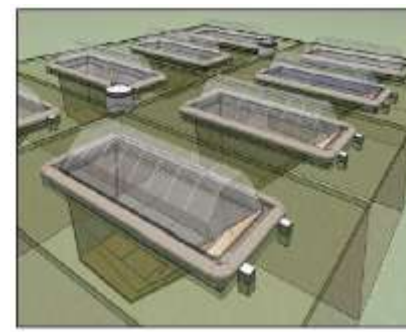

Process flow diagram of GICON Biogas Process
(http://www.gicon.de/uploads/tx_sbdownloader/Biogas_GICON_USA_02.pdf)

# High-solids Multi-stage

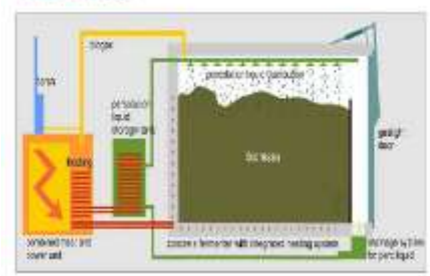
- Advantages
  - General advantages of multi-stage systems
    - Can optimize process stages separately
    - Can incorporate high-rate methanogenesis technologies
    - Higher OLR
    - Higher methane production rates
  - General advantages of high-solids systems
    - Dilution water often not required
    - Systems are more robust
    - Minimal pretreatment requirements
- Disadvantages
  - General disadvantages of high-solids systems and multi-stage systems
    - Higher capital and operating costs
    - More expensive materials handling equipment

# Landfill-Based AD

- Landfill cell designed to operate as AD reactor with source-separated organic waste
- Low initial/capital costs
- Slower waste conversion → lower energy yield

The Process



**Images from Yazdani, 2010**

# Landfill-Based AD

- Advantages
  - Can be located at landfill site and utilize existing infrastructure
  - May reduce need for additional infrastructure for gas collection
  - Lower capital costs than in-vessel AD
  - Has been demonstrated at pilot scale for green waste in the US
  - Can generate compost post-digestion in single digester cell
- Disadvantages
  - Larger footprint and retention time than in-vessel AD
  - Not yet demonstrated at full scale for food waste

# Material Handling Systems

- Currently available European systems generally require extensive pre- and post-digestion handling
  - Receiving: manual or robotic sorting to remove bulky/harmful materials (metals or plastics)
  - Particle size reduction: pulping, grinding, sieving, or biomixers
  - Separation: Magnetism, density (typically for low-solids) or size

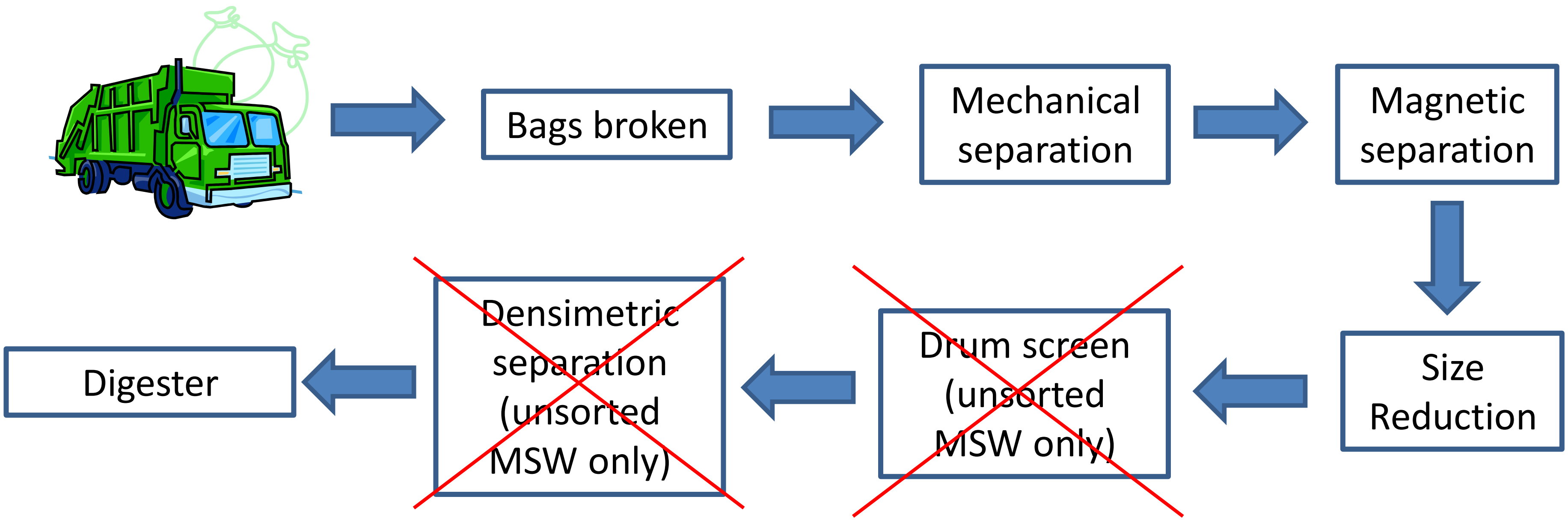



Diagram based on Bassano, Italy pre-processing diagram as depicted by Bolzonella et al., 2006.

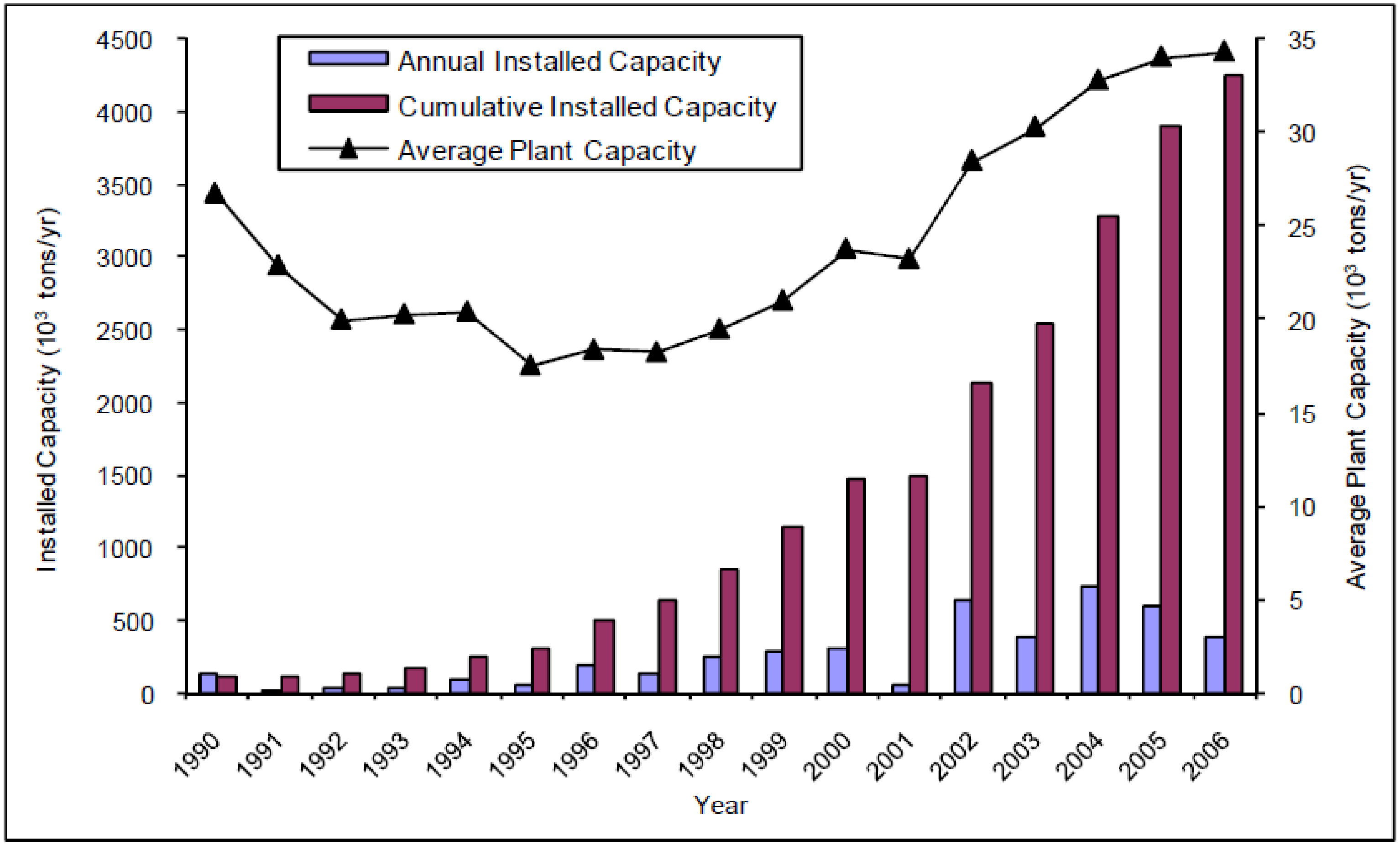

**Figure 6. Dry digester material handling equipment.**
Clockwise from top left: staging area with robotic claw; rotating biomixer drum; overs from trommel screen sieves; high-speed drum with integrated sieve and magnetic separator; high-solids slurry pump; feed mixer with steam injection; and dosing unit with steam injection and high-solids slurry pump.

**Images from Rapport et al., 2008**

# History & Current International AD Projects for MSW

- Europe
  - Over the past 25 years, AD applications to MSW/OFMSW have expanded due to waste disposal policies and high landfill tipping fees.
  - Market preference for single-stage processes and dry process. Batch systems are very uncommon.
- Canada
    - BTA model plants for 25,000 MT/y in Toronto
    - BTA model plant designed for 30,000-150,000 MT/ y in Newmarket, Ontario
- Projects have also been built in Japan and Australia.

# Solid Waste Anaerobic Digester Capacity in Europe




124 plants with capacity > 3,000 MT/y installed as of 2006.

**Figure from Rapport et al., 2008**

# History & Current US AD Projects for MSW

- Historical
  - 1970s: Refuse Converted to Methane (RefCoM) pilot project in Pompano Beach, Fl.
  - 1980s: Pilot, multi-stage AD project at Walt Disney World (Gas Technology Institute).
  - 1990s:
    - Pilot two-stage digester at Illinois Institute of Technology
    - Pilot thermophilic, high-solids, digester at UC Davis (Microgen Corp.)
    - Pilot high-solids, thermophilic digester in Stanton, Ca
- Current
  - BIOFerm Energy Systems system at the University of Wisconsin
  - BioConverter Systems LLC. AD projects in Los Angeles and Lancaster, CA.
  - SMARTFERM System in City of San Jose

# City of San Jose – Zero Waste

## Goal: Zero Waste to Landfill

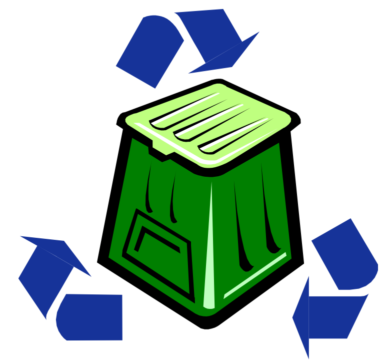
Food + Some Yard Waste

Anaerobic Digester

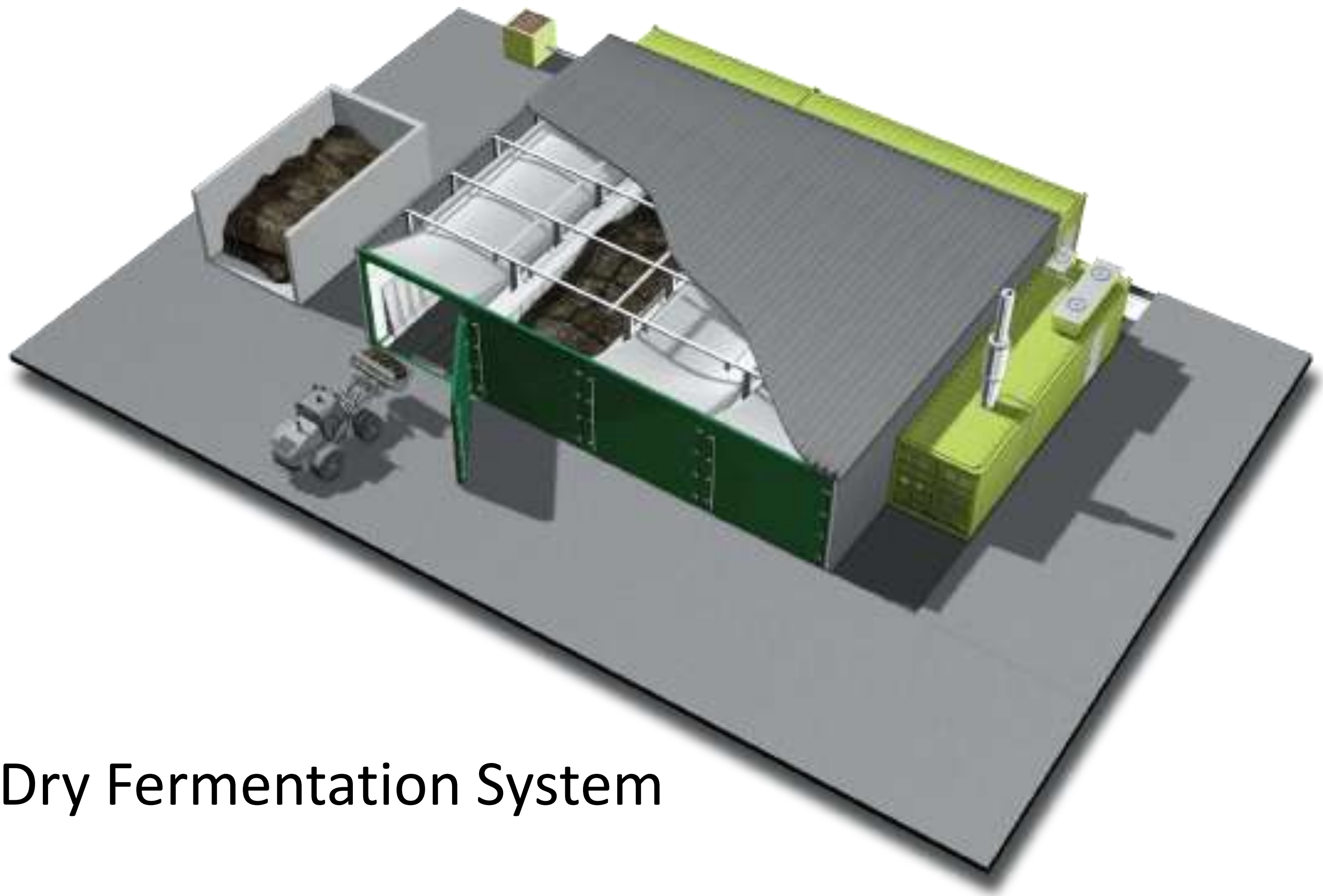
$CH_4$

Grass Clippings
And Other Yard Waste


Inorganics



# San Jose: SMARTFERM Process



Dry Fermentation System

# Summary and Conclusions

- A range of AD technologies are available, but applications to OFMSW in the US remain limited.
- Current projects (San Jose, Zero Waste) will be a source of US-relevant data and expand US-based knowledge of how to design and operate AD systems for the solid waste management sector.
- Landfill-based anerobic digestion may be a viable option that can be constructed at landfills to treat material anaerobically and then aerobically.

# Selected References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