Anaerobic Digestion Overview: Feedstocks to Biogas

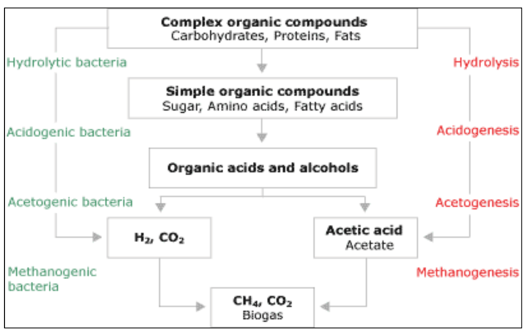
Tom Kraemer – June 4, 2012

Why consider anaerobic digestion?

- We can extract clean energy from the wastes
- AD produces biogas, which contains methane, the same thing as natural gas
- AD fits in with composting – materials and water go from digester to compost.
- AD makes composting faster.
- Enclosed system for odor control
- Pathogen reduction in enclosure

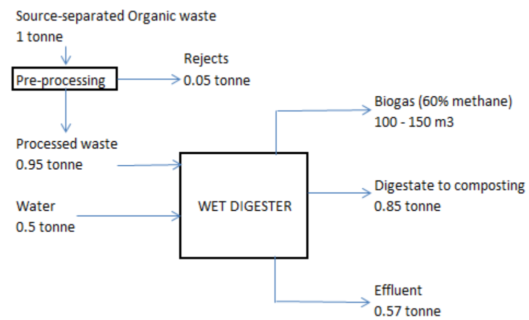
Microbes work for free

The Biochemistry of Anaerobic Digestion



Optimal pH
4.8 to 5.0
5.5 to 6.0
5.5 to 6.0
6.5 to 7.2

Overall Process and Mass Balance



Steps in the Anaerobic Digestion Process

1.Feedstock Receiving and Processing

2.Anaerobic Digestion

3.Biogas Capture and Utilization

4.Digestate Handling

What Feedstocks are Suitable for Anaerobic Digestion?

- Good Feedstocks Are Rapidly Degradable by Anaerobic Bacteria:
  - Food processing wastes
  - Pre-consumer and post-consumer food waste
  - Fats, oil and grease
  - Manures
  - Liquids and solids
  - In general, high in sugars, starches, proteins, oils.
- Poor Candidates for Anaerobic Digestion:
  - Yard waste
  - Woody waste
  - Paper and plastics
  - Knives, forks and spoons

Feedstock Processing

- Depends on digester technology
- Depends on feedstock
- General requirements:
  - 1. Debag – trommel with knives is one technology, or manual
  - 2. Size reduction –
    - Shredding (slow speed, larger size output)
    - Grinding (high speed, smaller size output)
    - Screening (small “unders”, large “overs”)
  - 3. Contaminant removal
  - 4. Water addition

Types of Anaerobic Digestion for Organic Waste

Dry AD

Wet Low-Solids e.g. Dairy

Wet High-Solids or Dry Pumpable

Wastewater treatment plant digester

Basic categories of digester used for MSW organics

- **Water Content is Most Important Parameter**
  - Dry – solids (more than 40% solids)
  - Wet – high solids, or Dry Pumpable (20 to 40% solids)
  - Wet – low solids (less than 20% solids)

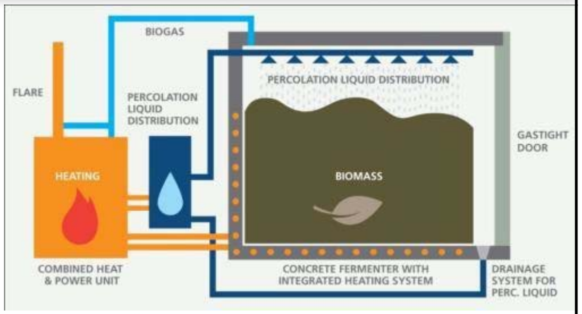
Digesters designed for any of the above water contents can also be designed for any of the following:

- **Operating Temperature**
  - Mesophilic: 30° to 38° C, optimal at 35° C
  - Thermophilic: 50° to 65° C, optimal at 55° C
- **Single Stage vs. Multiple Stage**
  - Organics Digestion Generally Limited to Two-Stage
  - Stages Optimized for Different Microbial Populations

How to Decide?

- HOW WET? - the first decision to make
- Feedstocks generally determine whether dry or wet, and how wet.
  - Food wastes generally can be handled by dry technologies, including stackable dry and pumpable dry technologies
  - Dry stackable technologies require source of "structural" material, such as ground yard waste
  - Manures, liquid or slurry food processing wastes require wet technologies
- Wetter always means more wastewater and more energy consumption
- For deciding meso- vs. thermophilic and single vs. multiple stage, more details are required. Let's look at the details.

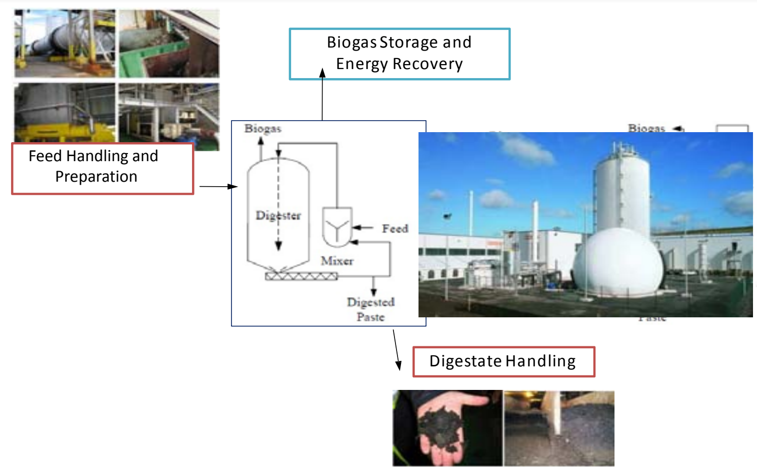
Dry Anaerobic Digestion



Dry Anaerobic Digestion

- Solids content 40% or greater – must be “stackable” - Food waste mixed with shredded yard wastes to percolate.
- Capacities: 10,000 tpy to 200,000 tpy
- Footprint: 3,000 sq. m. for 15,000 tpy system (1 ha/50k tpy)
- Feedstock preparation: Size reduction to 5 to 8 inches. Avoid aggressive size reduction
- Feedstocks are loaded with front end loader
- Processing Times: 14 to 28 days
- Wastewater: 20 to 30 litres per tonne of waste, 2,000 to 5,000 mg/l BOD5, 0 to 5,000 mg/l SS
- Digestate: Solid material, 50% to 60% moisture, can be composted without dewatering

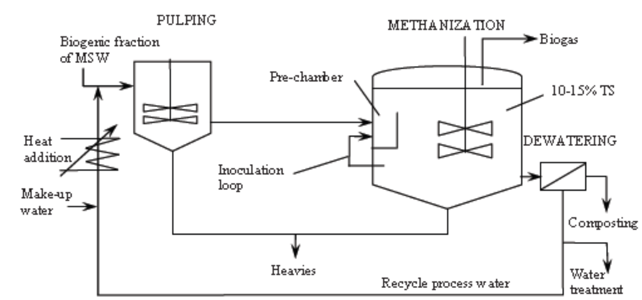
Wet High-Solids (or Pumpable Dry) Anaerobic Digestion



Wet High-Solids or Dry Pumpable

- 20% to 40% solids – Plug Flow – must be pumpable
- Good for feedstocks that are liquid or slurry upon arrival
- Capacities from 3,000 to 250,000 wet tonnes/yr
- Footprint of 5 ha for large end of range
- Feedstock preparation: Size reduction to 5 cm or less
- - Processing times: 14 to 28 days
- - Wastewater
  - production: Up to 300 litres per tonne of waste
  - characteristics: 1,500 mg/l BOD, 3,000 mg/l SS.
- Digestate can be dried and used as fertilizer, or composted

Wet Low-Solids Anaerobic Digestion



Continuously Stirred Tank

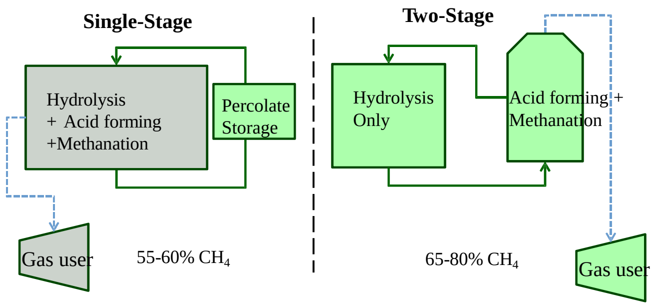
Wet Low-Solids Anaerobic Digestion

- 2% to 20% solids - liquid
- Good for feedstocks that are liquid upon arrival
- Capacities from 30,000 to 250,000 wet tonnes/yr
- Footprint of 5 ha for large end of range
- Feedstock preparation: Size reduction to 5 cm or less
- - Processing times: 30 to 40 days (hydraulic retention time)
- - Wastewater
  - production: Up to 500 litres per tonne of waste
  - characteristics: 1,500 mg/l BOD, 3,000 mg/l SS.
- Digestate must be dewatered and can then be dried and used as fertilizer, or composted

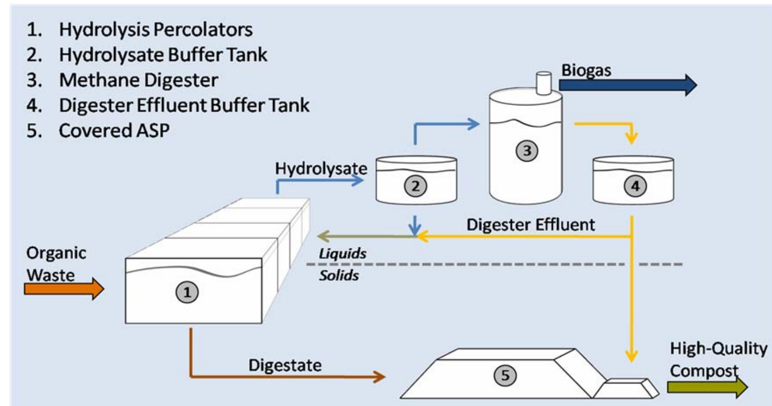
Advantages/Disadvantages

AD Technology	Advantages	Disadvantages
DRY	•"Contaminant" materials OK (plastic, metals, rocks) •Handles solid "stackable" wastes with little pretreatment •Negligible wastewater •More energy efficient than other AD systems	•Digestate requires composting at back end •Separation of contaminants for saleable compost •Requires mixing with shredded yard wastes
WET HIGH SOLIDS	•"Contaminant" materials OK (plastic, metals, rocks) •Handles liquid wastes and slurries •Less wastewater than wet low solids digestion •More energy efficient than wet low solids	•Slurry typically is not completely mixed – uneven digestion if not carefully managed •Produces more wastewater than dry digestion •Less energy efficient than dry digestion
WET LOW SOLIDS	•Handles liquid wastes and slurries •Uses unused capacity in WWTP sludge digesters – increasing cost effectiveness and energy efficiency	•Cannot generally handle waste with "contaminant" material (plastic, metals, rocks) •Requires significant pretreatment and operational care – can "upset" biosolids digestion •Solids in SSO may form a floating mat in WWTP digester where microbes cannot easily digest them.

Single vs. Two-Stage HSAD



Two Stage Anaerobic Digestion



Advantages/Disadvantages of One-Stage vs. Two-Stage Anaerobic Digestion Systems

One Stage Anaerobic Digestion Systems	Two Stage Anaerobic Digestion Systems
Advantages • Lower capital cost • Easier to operate • Less technical failures	Advantages • Potentially higher gas yields • More breakdown of biodegradable material under optimal conditions
Disadvantages • Conditions for two stages are not optimized • May lead to somewhat lower biogas yields	Disadvantages • Higher cost • More technical complexity • More technical failures

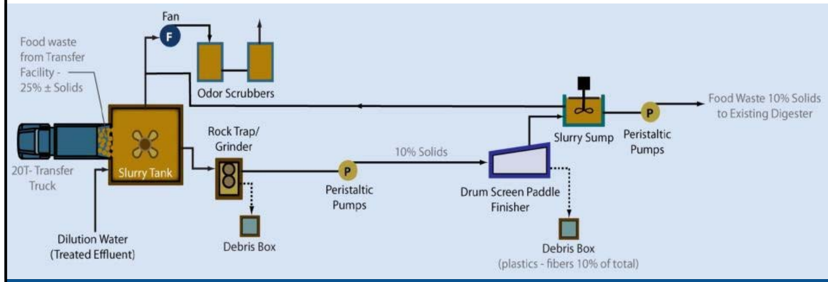
Mesophilic vs. Thermophilic Designs

Mesophilic: 30° to 38° C, optimal at 35° C
Thermophilic: 50° to 65° C, optimal at 55° C

Mesophilic AD	**Thermophilic AD**
Advantages - More robust set of organisms - Operation easier to stabilize	Advantages - Biogas production can be more than double mesophilic - Faster throughput = less capital cost for same
Disadvantages - Slower reaction = slower throughput - Lower rate of biogas production	Disadvantages - Requires more expensive, high temperature materials - Harder to control - can "overshoot"

Co-digestion With WWTP Biosolids

- Requires careful pre-processing – WWTP digesters can be damaged by highly fibrous material, metal, plastic, etc
- Cannot exceed capacity of WWTP digesters for flow, solids loading, or biogas handling
- Proven in several projects
- Detailed study of a long-term project shows biogas production higher than sum of separate biosolids and food waste projections.



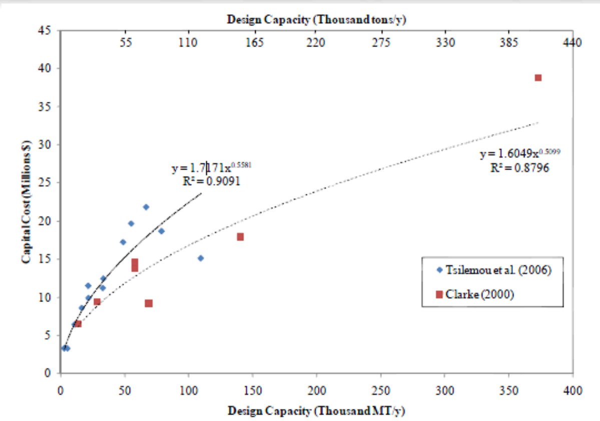
Costs - Dry AD Systems

Data on dry AD systems is very sparse – not published
Technology changing rapidly
Very important to get project specific cost estimates.

The following are averages from vendor-supplied preliminary quotes from a recent CH2M HILL feasibility study:

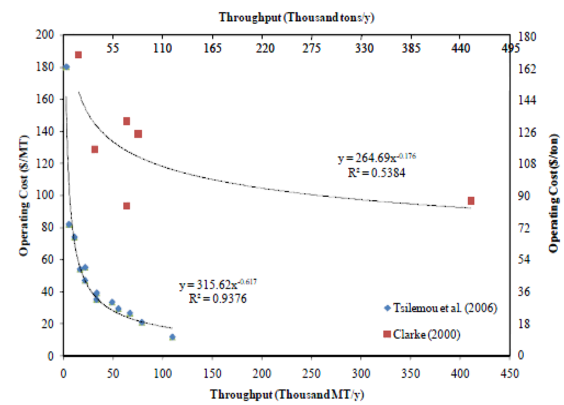
Dry AD System costs – AD system only (not site work)		
Tonnes/year	10,000	40,000
Capital	$ 4,900,000	$ 11,900,000
Operating	$ 220,000	$ 443,000

Wet AD Systems – Capital Costs (2007)



Includes all project costs

Wet AD Systems – Operating Costs (2007)



Includes all project costs

How to use biogas?

- Cleanup to pipeline quality
  - Remove CO_2
  - Remove sulfur
  - 98% - 99% CH_4 required
- 0.4% O_2 max!
- Vehicle Fuel – CNG
  - Remove CO_2, sulfur
  - Less stringent req'ts for O_2 and trace constituents
  - High pressure
- Combined Heat and Power
  - Reduce sulfur to 100 ppm
  - No need to remove CO_2

How much energy can we get from organic wastes?

- Biogas is 60% to 70% methane
- Typical yields are 70 m3 methane per tonne of raw food waste. – this can vary a lot!
- Energy content of methane is about 37 MJ/m3
- Conversion of biogas to electricity using engine-generator sets is about 35% efficient.

Electricity: (70 m3 CH_4) X (37 MJ/m3) X (1kWh/3.6 kJ) X 0.35

= **250 kWh.** If we can get $0.10/kWh, then energy in food waste worth $25.00/tonne

Vehicle Fuel: 1 Gallon Gasoline = 4 m3 methane

(70 m3 methane) / (4 m3 methane/gallon)= **18 gallons gasoline**

At $4.00/gallon = $72/ton

Current Anaerobic Digestion Technologies Used for Treatment of Municipal Organic Solid Waste, California Integrated Waste Management Board, March 2008, p. 50.

Zhang et al, "Characterization of food waste as feedstock for anaerobic digestion," Bioresource Technology 98 (2007) 929–935.

Can Food Waste Power It's Own Collection and Processing?

YES! Food waste produces enough biogas to not only fuel the collection vehicle that picks it up, but also provide enough energy to power the biogas production process.

The numbers:

- Garbage truck: 2.8 miles or 4.5 km per gallon of diesel fuel
- 1 gal diesel = ~ 4 m3 of natural gas
- Digester: 70 m3 of methane per tonne of food waste (low end of range) Then (70m3/tonne) ÷ (4 m3/gal) X (4.5 km/gal) = 79 km/ tonne of food waste.

Average route is only 30 km - Energy to Spare!

But! What about digester operations and gas processing?
-Digester ops consume 18% of biogas energy
-CNG cleaning and pressurization consume 32% So, we still can drive 38 km with what's left Energy to Spare!

Food Waste Digestion – Biogas Projects Underway in North America

- Co-digestion
  - EBMUD – Operational since 2005 – commercial food waste delivered by Norcal – as of 2008, the only operational MSW food waste co-digestion project N. America
  - Central Marin Sanitation Agency/Marin Sanitary Service – Operational mid 2012
- Wet Digestion
  - Toronto Dufferin – low solids (<20%). 25,000 tonnes/year. Operational since 2002
  - Newmarket, ON (near Toronto) low solids. 150,000 tonnes/year since 2003.
  - Harvest Power – London, Ontario - under construction
  - Columbia Biogas, Portland, OR, 140,000 tons/yr commercial food waste. Construction starts late 2012
  - Columbia, SC. High solids. 48,000 tonnes/yr commercial food waste. Operational by end of 2012.
  - IEUA, Chino, CA, 200-500 tpd preconsumer food waste. Commissioning under way April 2012
- Dry Digestion
  - Oshkosh, WI – Operational since fall 2011 – Bioferm
  - Cedar Grove, Marysville WA – Construction starts June – Bioferm
  - Fraser Richmond, Vancouver – Operational in late 2012 – GICON
  - San Jose – Construction starts June – Eggersmann Kompoferm
  - Monterey – Under contract – Eggersmann Smartferm