Anaerobic Digestion

Biomass + Bacteria + Time = Biogas
Basic Anaerobic Digester System Flow Diagram

Digester Inputs
(manure, organic substrates)

Anaerobic Digester

Biogas
Conditioning to remove $H_2O$ & $H_2S$

Processing to remove $CO_2$

Biomethane (900-1000 BTU/scf)
Natural gas pipeline quality vehicle fuel (CNG/LNG), feedstock

Medium-BTU Biogas (600-700 BTU/scf)
Boiler, heater, chiller, etc.

Electricity
Internal combustion engine
(early stage: microturbines, fuel cells)

Recaptured Heat

Simplified Heat for Digester

Supplemental Heat for Digester

Digestate

Liquids

Solids

Solids Separator

Solids

Lagoon/Liquid Storage

Advanced Treatment

Fiber-based Products

Fertilizer (NPK)

Compost

Soil Amendment

Bedding

Concentrated Fertilizer

Lagooon/Liquid Storage

Discharge

Reuse

Fertilizer for field or greenhouse crops, flush water

Farm or Neighbor Use
Building heating, greenhouse, food storage, adjacent commercial/industrial needs, etc.

Energy Company
Electric utility, natural gas pipeline, vehicle fueling station

All of the opportunities presented will not be appropriate for all digester systems based upon technical and financial constraints.
Definitions:

• **Anaerobic**: without oxygen

• **Anaerobic organisms or anaerobes**: organisms that do not require oxygen for growth
  – May react negatively or die if oxygen is present

• **Methanogenesis or biomethanation**: the formation of methane by microbes
  – Important, widespread form of microbial metabolism
  – In most environments, the final step in decomposition of biomass
Why consider AD?

**Anaerobic Digestion** is a biological treatment process to:

- Reduce odor
- Improve manure storage and handling characteristics
- Reduce waste disposal costs
- Meet regulatory requirements
  - Reduce landfill use
  - Reduce greenhouse gas emission
  - Reduce effluent nutrients and pathogens
- Produce energy
What can be digested?

Biological materials in slurry

- Manure
- Food processing waste
- Municipal wastewater
- Purpose-grown crops
What do I need for AD?

- **Feedstock**
  - 500 cows
  - 2,000 hogs w/ anaerobic lagoons
  - 5,000 hogs w/ deep pits

- **Anaerobic Digester facility**

- **Biogas collection system**

- **Use for biogas**

- **Use for effluent solids & liquids**
How does AD work?

• **Biological process**
  
  – Operating criteria
    
    • Consistent stream of inputs
    • Solids < 15% by weight
    • pH 7.0
    • Temperature 95F
      
      – Each 20°F decrease cuts gas production 50%
        
        » Doubles retention time
  
  – 30 days retention time
Anaerobic digesters

- Covered lagoon
- Tank
Digestate products

Liquid

– Land application
– Wastewater treatment plant
Digestate products

Solids

- **Digested solids** can be removed from the digester effluent with a solids separator.
- Commonly used as livestock bedding, soil amendments or biodegradable planting pots.
- Emerging applications for effluent solids include use in structural building materials, such as deck boards and particle board.

http://www2.epa.gov/agstar/learn-about-biogas-recovery#adwork
Biogas composition

• **Methane: CH$_4$**
  – Landfills 20-40% Methane
  – Most digesters 40-50% Methane
  – High yield digesters 75% Methane

• **Carbon dioxide: CO$_2$**
  – Doesn’t burn

• **Contaminants - hydrogen sulfide: H$_2$S**
  – Sulfurous rotten egg odor
  – Forms sulfuric acid: corrosive to systems & engines

• **Water vapor**
  – Contributes to corrosion
  – Reduces gas energy content
Biogas scrubber

Remove $H_2S$
- Bubble gas through reagent
- Precipitate sulfur
- Reuse reagent

Remove $CO_2$
- Dissolve $CO_2$ in water

Biogas handling system

• Biogas transported from digester directly to a gas use device or to a gas treatment system
• In most cases, only treatment is to remove excess moisture prior to combustion
• Hydrogen sulfide, other contaminants should be removed from the gas to prevent corrosion of the combustion device

http://www2.epa.gov/agstar/learn-about-biogas-recovery#adwork
Biogas dryer

Remove moisture

• Biogas at digester has a very high water vapor content, between 4 and 8%
• Moisture traps remove some moisture
• Drying to a dewpoint of 5°C reduces moisture to 1%, increasing the methane content by 5%, in turn increases the electrical output by 5%
• Removal of moisture and contaminants reduces corrosion, engine oil changes, etc.

https://parkerid.com/parker/jsp/documentdisplay.jsp?mgmtid=0fc57b8452dcf310VgnVCM100000200c1dacRCRD
Biogas for heat

Fuel for boilers
- Simplest gas utilization
- Must have a use for the heat energy
Biogas use

Electricity and Heat

• Biogas is most often used to generate electricity
• Waste engine heat can be recovered to heat digesters or adjacent buildings
• Biogas can be fired directly in boilers or heaters as a replacement for propane

http://www2.epa.gov/agstar/learn-about-biogas-recovery#adwork
Biogas for power generation

Natural gas capable engine

- Alternator produces AC current 24/7
  - Cat ratings 143 – 4,300 ekW
- Feeds all production to utility grid
  - Requires utility contracts
- Waste heat utilization
  - Digester heating
  - Water heating
  - Space heating
- Flare excess or during maintenance

Caerpillar.com
Biogas for transportation

**CNG**: 3,000 – 6,000 psi

– cost of CNG conversion kit often $8,000 on passenger cars and light trucks

http://www.afdc.energy.gov/fuels/natural_gas_cng_stations.html
Biogas for transportation

LNG:

– Cryogenic: approx −260 °F
  • Expensive, heavy insulated tanks
– maximum transport pressure 4 psi
– fuel delivered to vehicles at 30 to 120 psi
– protective clothing, face shield, & gloves when fueling

http://www.afdc.energy.gov/fuels/natural_gas_infrastructure.html
Biogas for transportation

Hydrogen conversion

– Fuel cell vehicles
– High pressure storage: 5,000 psi
– Cryogenic LH2: -420°F

http://www.eoearth.org/view/article/153626
Sell to the gas utility

**Diagram: Biogas Flow**

- **Biogas**
  - Onsite Use
  - Offsite Use
- **Biogas Conditioning Facility**
- **"Treated" Biogas**
  - Power Generation
  - Boiler, Other
  - Pipeline Injection

**Biomethane** (aka Renewable Natural Gas or Pipeline Quality Gas)

**Illustration for Landfill Diverted Waste**

<table>
<thead>
<tr>
<th>Gas Composition and Heating Value</th>
<th>Biogas</th>
<th>&quot;Treated&quot; Biogas</th>
<th>Biomethane*</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH4</td>
<td>62.0%</td>
<td>62.0%</td>
<td>98.5%</td>
</tr>
<tr>
<td>CO2</td>
<td>37.6%</td>
<td>37.6%</td>
<td>0.8%</td>
</tr>
<tr>
<td>O2, H2, N2, Others</td>
<td>0.4%</td>
<td>0.4%</td>
<td>0.7%</td>
</tr>
<tr>
<td>Heating Value (btu/scf)</td>
<td>625</td>
<td>625</td>
<td>990+</td>
</tr>
</tbody>
</table>

**Two of the Key Trace Constituents**

<table>
<thead>
<tr>
<th></th>
<th>Biogas</th>
<th>&quot;Treated&quot; Biogas</th>
<th>Biomethane</th>
</tr>
</thead>
<tbody>
<tr>
<td>H2S</td>
<td>300 ppm</td>
<td>1 ppm</td>
<td>1 ppm</td>
</tr>
<tr>
<td>Siloxanes</td>
<td>4,000 ppb</td>
<td>70 ppb</td>
<td>Non-detectable</td>
</tr>
</tbody>
</table>

* Gas composition and trace constituent limits will/may differ by utility.
Sell to the gas utility

Organic Waste

Digester

Biogas Conditioning Facility

Biomethane Piping

Utility Interconnection

SoCalGas Pipeline Network

RPS Certified Generation Plant

No!

Eligible for Investment Tax Credit?

Yes

Cogeneration System
Biogas use

Flare Excess

• Burn excess biogas
• Burn biogas during periods when the primary gas use device is undergoing maintenance or repair
• In cases where the primary purpose of the digester is to control odor or generate carbon credits, all of the biogas may be flared

http://www2.epa.gov/agstar/learn-about-biogas-recovery#adwork
OK, so I want to do this!

Typical AD users:

– Municipal wastewater treatment plant
– Municipal landfill
– Large slaughter operation
– Agriculture:
  • 500 cows
  • 2,000 hogs w/ anaerobic lagoons
  • 5,000 hogs w/ deep pits
OK, so I want to do this!

<table>
<thead>
<tr>
<th>Manure Type</th>
<th>Definition</th>
<th>Compatible with Anaerobic Digestion?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid Manure</td>
<td>Diluted to solids content less than 5%</td>
<td><strong>Maybe.</strong> Can be adapted for biogas production in warm climates. In colder climates, may be limited to gas flaring for odor control unless other organic materials are codigested.</td>
</tr>
<tr>
<td></td>
<td>Typically “flushed” using fresh or recycled water</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Can be pumped to treatment and storage tanks, ponds, lagoons or other suitable structures.</td>
<td></td>
</tr>
<tr>
<td>Slurry Manure</td>
<td>Diluted to solids content 5-10%</td>
<td><strong>Yes.</strong> For biogas recovery and energy production, depending on climate and dilution factors.</td>
</tr>
<tr>
<td></td>
<td>Usually collected by “scraper” system</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Can be pumped. Often treated or stored in tanks, ponds or lagoons prior to land application.</td>
<td></td>
</tr>
<tr>
<td>Semi-Solid Manure</td>
<td>Handled as semi-solid, with solids content 10-20%</td>
<td><strong>Yes.</strong> Fresh scraped manure (less than one week old) can be used for biogas production in all climates. Can be heated to promote bacterial growth.</td>
</tr>
<tr>
<td></td>
<td>Typically scraped, water not added to manure</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Typically stored until spread on fields.</td>
<td></td>
</tr>
<tr>
<td>Solid Manure</td>
<td>Solids content greater than 20%</td>
<td><strong>Maybe.</strong> Aged solid manure or manure that is left “unmanaged” or allowed to dry is not suitable for traditional digesters. Regularly collected manure could be used.</td>
</tr>
<tr>
<td></td>
<td>Handled as a solid by a scoop loader.</td>
<td></td>
</tr>
</tbody>
</table>

https://www.epa.gov/agstar/anaerobic-digestion-right-your-farm
Significant investment

Planning:
  – Energy contracts
  – Construction
  – Byproducts utilization

Facilities:
  – Land & buildings
  – Materials handling
  – Gas processing / storage
  – Gas utilization
  – Digestate utilization
Commitment

Long-term commitment

– Daily system management / oversight
  • Mechanical systems operation / maintenance / upgrades
  • Biological systems monitoring
    – Consistent feeding, temp, oxygen exclusion, etc.
  • Energy systems monitoring
  • Communications
    – Energy customers
    – Effluent customers
    – Creditors
    – Regulators
Effluents

Sludge or effluent

- Rich in nutrients (NH$_3$, P, K, trace elements)
- Excellent soil conditioner
- Can use as livestock feed additive when dried
- Toxic compounds (pesticides, etc.) in digester feedstock may become concentrated in the effluent
  - Test the effluent before using on a large scale

http://www.daviddarling.info/encyclopedia/A/AE_anaerobic_digestion.html
Organic waste collection

Best suited for farms that collect manure:

– As slurry or semi-solid;
– At a single point (a lagoon, pit, pond, tank or other similar structure);
– Every day or every other day;
– Free of large amounts of bedding or other materials (e.g., rocks, stones, straw or sand), which can clog the pipes of the digester and hinder operation
– May be pre-treated before entering a digester to adjust the total solids content by adding water, separating solids, mixing or heating

http://www2.epa.gov/agstar/learn-about-biogas-recovery#adwork
Waste collection system

Other materials may be harmful to anaerobic bacteria:
- feed additives with antibiotics
- equipment cleaning and maintenance compounds

http://www2.epa.gov/agstar/learn-about-biogas-recovery#adwork
Covered lagoon digester

Methane is recovered and piped to the combustion device from a lagoon with a flexible cover

- Some systems use a single cell for combined digestion and storage

http://www2.epa.gov/agstar/learn-about-biogas-recovery#adwork
Plug flow digester

Long, narrow concrete tank with a rigid or flexible cover

- Built partially or fully below grade to limit the demand for supplemental heat
- Used at dairies that collect manure by scraping

http://www2.epa.gov/agstar/learn-about-biogas-recovery#adwork
Digester design

**Complete mix digesters** use enclosed, heated tank with a mechanical, hydraulic or gas mixing system.

- Work best when some dilution of the excreted manure with water (e.g., milking center wastewater).

http://www2.epa.gov/agstar/learn-about-biogas-recovery#adwork
Who uses AD?

Operational Biogas Systems in the U.S. - Agricultural, Landfill, and Wastewater Systems Only

http://americanbiogascouncil.org/biogas_maps.asp
Who uses AD?

Operational Biogas Systems in the U.S. - Agricultural Systems Only

www.americanbiogascouncil.org/biogas_maps.org

http://americanbiogascouncil.org/biogas_maps.asp
Who uses AD?

[Map showing Operational Biogas Systems in the U.S. - Landfill Systems Only]

[Image link: http://americanbiogascouncil.org/biogas_maps.asp]
Who uses AD?

Operational Biogas Systems in the U.S. - Wastewater Systems Only

http://americanbiogascouncil.org/biogas_maps.asp
Who uses AD?

http://americanbiogascouncil.org/biogas_maps.asp
Perdue Farms, Cromwell KY
Perdue Farms Inc.
Biogas to Energy Project Summary
Industrial Facility Retrofit Showcase
Cromwell, Kentucky

- Total Project Cost: $1.375 Million
- Kentucky Cabinet for Economic Development Grant: $240,000
- Annual Impact
  - Reduction of 30,300 tons of equivalent CO2 greenhouse emissions
  - $760,000 of revenue from electric generation
  - 5,600 MWH of electricity generated from renewable biogas
  - $154,000 saved in natural gas costs
- Interval to pay back total project cost, less grant funding: 15 months

http://energy.ky.gov/Documents/Perdue arms Case Study.pdf
Keystone Foods, Albany KY
Keystone Foods, Albany KY

- Dedicated boiler system captures biogas via anaerobic digestion
- More energy used in-house to heat water for production
- Results:
  - 290,000 gallons of liquid propane offset
  - 1,700 metric tons of CO₂ not released
  - $500,000 in annual savings
Memphis Waste Water Plant

Methane gas burned at Allen Fossil Plant replaces more than 20,000 tons of coal per year.
# TVA Green Power Switch

## Megawatt-hours (MWh) generated

<table>
<thead>
<tr>
<th>Biogas Generation</th>
<th>June 2012-September 2013</th>
<th>Total Program Generation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allen Steam Plant</td>
<td>42,078</td>
<td>295,004</td>
</tr>
<tr>
<td>Generation Partners (Biogas)</td>
<td>78,463</td>
<td>119,563</td>
</tr>
<tr>
<td>Total Methane Generation</td>
<td>120,541</td>
<td>414,567</td>
</tr>
</tbody>
</table>

Summary

• Anaerobic digestion can be a viable waste to energy option, if:
  – There is a steady stream of suitable biological material
  – There is a means of using the biogas produced
  – There is a commitment to provide needed daily management
  – There are financial resources needed to install the system
  – Tax credits and incentives may not favor all options to the same extent

• Consult:
  – engineers with successful AD projects
  – Financial advisors familiar with energy systems financing
Learn more

• US EPA AgSTAR
  https://www.epa.gov/agstar

• USDA Anaerobic Digesters blog
  http://blogs.usda.gov/tag/anaerobic-digesters

• USDA Rural Development – Rural Energy for America Program (REAP)
  – http://www.rd.usda.gov/programs-services/rural-energy-
    america-program-renewable-energy-systems-energy-efficiency

• NREL
  www.nrel.gov
For more info

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