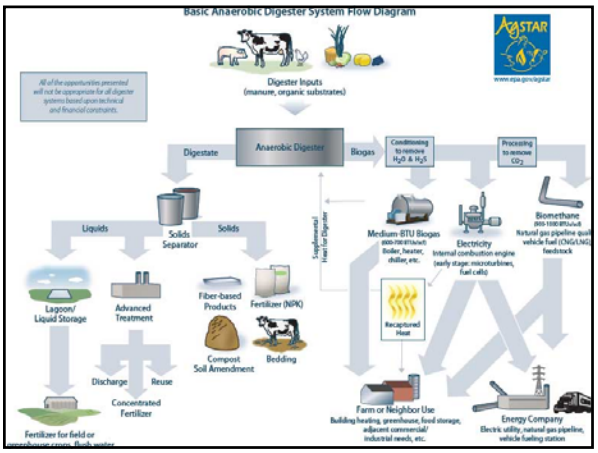


Definitions:

- **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 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

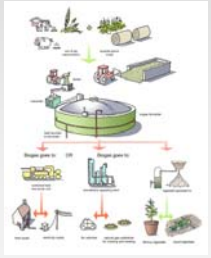
What can be digested?

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

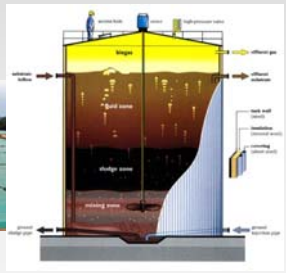


How does AD work?

- **Biological process**
  - Operating criteria
    - Consistent stream of inputs
    - Solids < 15% by weight
    - pH 7.0
    - Temperature 95F
      - Each 20F 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_2S**
  - Sulfurous rotten egg odor
  - Forms sulfuric acid: corrosive to systems & engines
- **Water vapor**
  - Contributes to corrosion
  - Reduces gas energy content

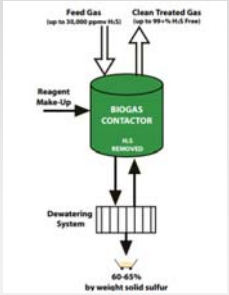
Biogas scrubber

Remove H_2S

- Bubble gas through reagent
- Precipitate sulfur
- Reuse reagent

Remove CO_2

- Dissolve CO_2 in water



http://eco-tec.com/wp-content/uploads/2012/08/BRGP900_BgPur.pdf

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

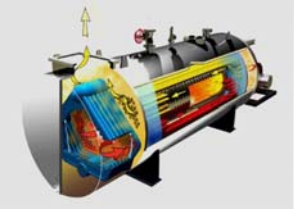
- Biogas at digester has a very high water vapor content, between 4 and 8%
- Moisture traps remove some moisture
- Drying to a dewpoint of 5°C reduces moisture to 1%, increasing the methane content by 5%, in turn increases the electrical output by 5%
- Removal of moisture and contaminants reduces corrosion,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

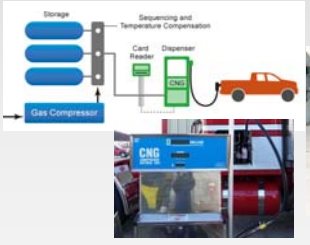
- Alternator produces AC current 24/7
  - Cat ratings 143 – 4,300 ekW
- Feeds all production to utility grid
  - Requires utility contracts
- Waste heat utilization
  - Digester heating
  - Water heating
  - Space heating
- Flare excess or during maintenance

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

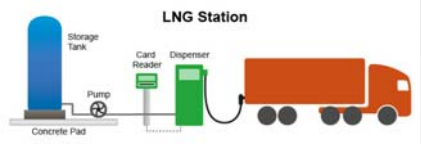


http://www.afdc.energy.gov/fuels/natural_gas_cng_stations.html

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

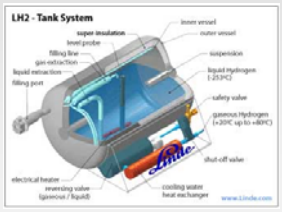


http://www.afdc.energy.gov/fuels/natural_gas_infrastructure.html

Biogas for transportation

Hydrogen conversion

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



http://www.eoearth.org/view/article/153626

Sell to the gas utility

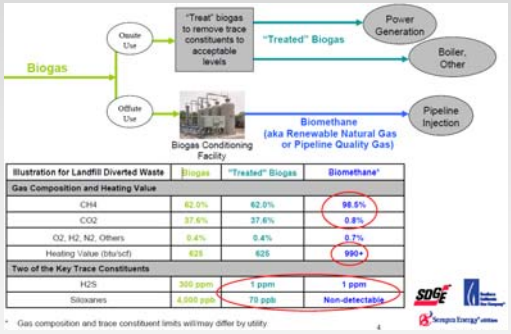
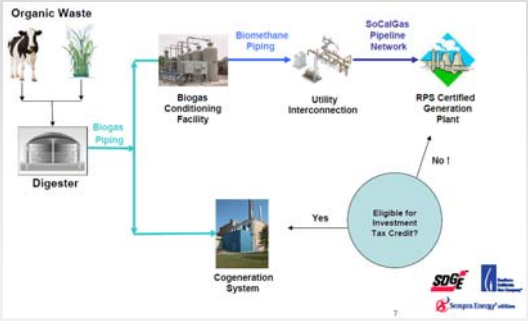


Illustration for Landfill Diverted Waste	Biogas	"Treated" Biogas	Biomethane*
Gas Composition and Heating Value			
CH4	62.0%	62.0%	98.5%
CO2	37.6%	37.6%	0.8%
O2, H2, N2, Others	0.4%	0.4%	0.7%
Heating Value (btu/scf)	625	625	990+
Two of the Key Trace Constituents			
H2S	300 ppm	1 ppm	1 ppm
Siloxanes	4,000 ppb	70 ppb	Non-detectable

* Gas composition and trace constituent limits will/may differ by utility

Jim Lucas, Sempra Energy Utilities. 2011

Sell to the gas utility



Jim Lucas, Sempra Energy Utilities. 2011

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!

Manure Type	Definition	Compatible with Anaerobic Digestion?
Liquid Manure	Diluted to solids content less than 5% Typically "flushed" using fresh or recycled water Can be pumped to treatment and storage tanks, ponds, lagoons or other suitable structures.	**Maybe**. 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.
Slurry Manure	Diluted to solids content 5-10% Usually collected by "scraper" system Can be pumped. Often treated or stored in tanks, ponds or lagoons prior to land application.	**Yes**. For biogas recovery and energy production, depending on climate and dilution factors.
Semi-Solid Manure	Handled as semi-solid, with solids content 10-20% Typically scraped, water not added to manure Typically stored until spread on fields.	**Yes**. Fresh scraped manure (less than one week old) can be used for biogas production in all climates. Can be heated to promote bacterial growth.
Solid Manure	Solids content greater than 20% Handled as a solid by a scoop loader.	**Maybe.** 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.

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:

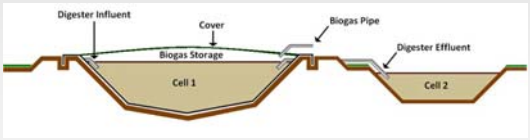
- feed additives with antibiotics
- equipment cleaning and maintenance compounds

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

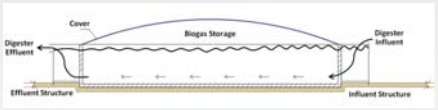


http://www2.epa.gov/agstar/learn-about-biogas-recovery#adwork

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

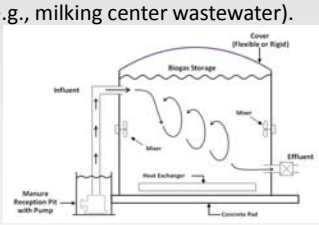


http://www2.epa.gov/agstar/learn-about-biogas-recovery#adwork

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?

http://americanbiogascouncil.org/biogas_maps.asp

Who uses AD?

http://americanbiogascouncil.org/biogas_maps.asp

Who uses AD?

http://americanbiogascouncil.org/biogas_maps.asp

Who uses AD?

http://americanbiogascouncil.org/biogas_maps.asp

Who uses AD?

http://americanbiogascouncil.org/biogas_maps.asp

Perdue Farms, Cromwell KY

Perdue Farms, Cromwell KY

PERDUE

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

Google Maps

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 CO_2 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 News, Winter 2015

TVA Green Power Switch

Megawatt-hours (MWh) generated

Biogas Generation	June 2012-September 2013	Total Program Generation
Allen Steam Plant	42,078	295,004
Generation Partners (Biogas)	78,463	119,563
Total Methane Generation	120,541	414,567

http://www.tva.com/greenpowerswitch/updates.htm

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 Devlopment – 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

Tim Prather
UT Extension
Biosystems Engineering & Soil Science Dept.
2506 E J Chapman Drive
Knoxville, TN 37996

tprather@tennessee.edu

energy.tennessee.edu