Anaerobic Digestion & Biogas

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1. INTRODUCTION

Food Waste to a Digester

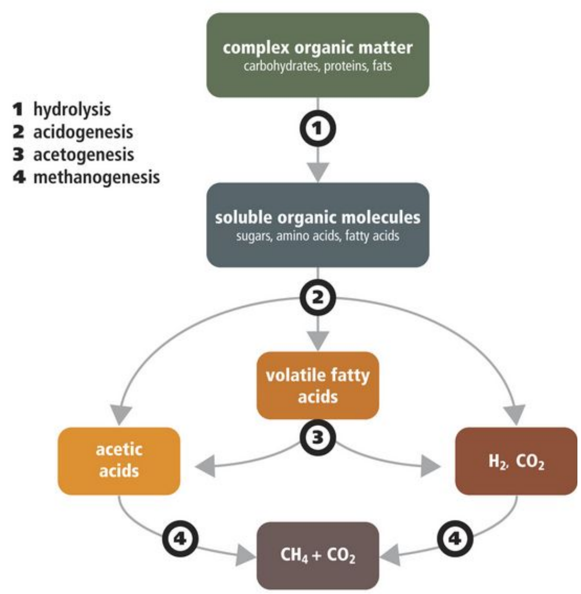
Biogas comes from the breakdown of organic matter in anaerobic environments such as in landfills, in nature, in the human body, and in engineered anaerobic digesters. Anaerobic Digestion (AD) is the breakdown of organic matter in the absence of oxygen. AD units come in many different styles, shapes and configurations with the commonalities being that they operate in the absence of oxygen, in a sealed vessel and operate at elevated temperatures. A common analogy is that food waste digesters operate quite like the human body's or ruminant animal's digestive system. The gas mixture that emanates from a digester is commonly referred to as biogas. The remaining solids and nutrient rich liquid is referred to as digestate. This document is focused on AD as an established means of converting organic matter to fertilizer and biogas.

Food waste is a common material used to feed digesters. A common pyramid for dealing with excess food is:

a. Feed People
b. Feed Animals
c. Generate Energy (send to a digester)
d. Produce Compost

AD is turning into an ever-popular recycling choice as an approach to get energy, compost and nutrient value out of discarded organics and helps control methane emissions which are a highly potent greenhouse gas. Biogas can be used as a fuel in gas pipelines, combusted to produce electricity or compressed into a vehicle fuel. The residual solids and liquid are good nutrient-rich crop fertilizers.

1.1 PROCESS CHEMISTRY



Steps in AD Process

The pathway to making biogas from waste is multi-step. First, the organic waste undergoes hydrolysis and acidification steps where large molecules are broken apart and organic acids are formed. Material at this phase would have a foul odor to it and be considered "rancid.” From there, other steps including acetogeneis and methanization occur where microbes called "acetogens" and "methanogens" generate methane gas. The acetogenesis phase converts organic acids to acetate. Methanogens are the key to making biogas but are slow growing and can cause operational issues if not tended to properly. Biogas is commonly a mix of both methane and carbon dioxide (CO_2). The compositions of biogas depend on the chemical pathway for digestion but usually range from 50-70% for methane with the balance being CO_2, hydrogen sulfide and other trace gases.

1.2 GAS YIELD

Wastes make different amounts of gas in a digester. Gas yields are fairly analogous to calorie value of foods as both pertain to energy values. In a digester, easy to digest carbohydrates such as pre consumer food waste from grocery stores can digest very rapidly and convert to methane quickly much like our bodies metabolize sugars and starches quickly. Other materials like proteins in waste meat or waste oils and fats can provide very significant energy potential but can take more time to degrade.

A common lab test to validate the potential gas yield of these various substrates is the Biomethane Potential Test, or BMP Test. The BMP test simulates a digester on the laboratory scale as a batch test. A waste sample is put in a sealed beaker, diluted, seeded with a bacteria inoculum, heated, and mixed for a number of weeks. Its resulting gas yield rate is traced over time. Knowing the BMP profile of the waste with a particular process is critical to modeling system gas output. There is significant data in industry literature on the gas yield of hundreds of different substrates.

To understand how gas comes from food waste one can come at it from a couple of perspectives. First one must appreciate that food waste can contain 60-90% water. The remaining fraction is the material that provides the gas yield. A ton of food waste that enters a digester will only yield gas from the Volatile Fraction, that being the carbonaceous fraction. Some will refer to the gas yield of a wet ton of matter delivered to a facility while others will refer to gas yield that comes from volatile fraction not including the water weight. The first would be considered the gas yield of "wet solids" the other would be considered the gas yield of the "volatile solids."

1.3 PROCESS MODELING

A number of digester computer-based performance models exist. Some are available for a fee and others are available for download at no cost. A process model is a key step in the typical stage-gated project development process where local area wastes are profiled and waste quantities are projected. By inputting projected tip fees, resulting energy and compost sales, projected Return on Investment (ROI) can be calculated to determine if a project meets investor financial metrics.

Running a number of iterations of the process model to optimize the local circumstances and nuances of a particular project are of paramount importance to optimizing digestion facility size. As all models can be subject to "Garbage In - Garbage Out" scenarios it is important to feed the models with good, hard costing information of system construction cost, projected energy sales and projected site tip fees to make educated decisions. Many of the free models work fine for project screening but once projects get past the screening stage and into the project sizing stage, these models become too complex for the no-cost models.

1.4 DIGESTION PROCESS

"Volatile Solids" are the components of the wastes that are amenable to converting to gas. These are different from the non-volatile fraction, also known as the ash fraction. Much as the volatile fraction of woody waste goes up in smoke in a fireplace, for example, the ash is the fraction which is left behind and not able to be volatilized. Digester designers require data on organic matter concentrations in feedstocks and project what fraction of the organics can convert to biogas. Roughly 40-60% of the organic matter or "volatile fraction" of the feedstock will convert to gas in the digester, given proper residence time. The more time the waste is allowed to digest in the system the more the conversion. Some molecules like cellulose and other fibrous material will sometimes resist breakdown in a digester but given the right conditions can be digested.

There is a tradeoff and balance between the amount of digestion time, the amount of energy one is able to produce and system costs.

1.4.1 LOADING RATES

A recent Cal Recycle study gives reference on loading rates used in anaerobic digesters. Loading rates they refer to include 0.02-0.05 pounds of volatile solids per gallon of digester tank volume each day.

Example: Loading rate of food waste into a 1 Million gallon digester:

- Assuming a food waste that was 70% water, 15% volatile solids and 15% nonvolatile (ash)
- Assume a mid loading rate of 0.025 lb. of volatile solids per gallon of digester volume daily
- As the food waste is 15% volatile one must first convert to total mass of food waste. That equates to 0.025/0.15 or 0.167 pounds of total food waste (or 2.6 ounces) per gallon of digester capacity each day.
- So, for example, a typical 1 Million gallon digester tank might have about 167,000 wet pounds (1,000,000 gallons x 0.167 pounds per gallon per day loading rate) or 83 wet tons of food waste fed to it each day at these loading rates.

Common reactor retention times range from as little as a few days to as much as a month or two. The loading rate and retention time varies with the type of waste and the type of digester being used.

1.4.2 GAS YIELD

A study from Sweden (Substrate Handbook 2009) quoted about shows that showed an average gas yield of 3.6 cubic of biogas would come from the digestion of a pound of typical food waste:

Example: Gas Yield and Power Generation capacity for a large, 40,000 ton per year food waste digester:

- 40,000 ton / yr. x 2000 lb. /ton = 80,000,000 lb./yr. total food waste fed into digester
- 80,000,000 lb. of food waste x 3.6 cubic feet per pound = 288 million cubic feet per year of gas generated
- 288 Million cubic feet of biogas per year is 555 cubic feet per minute (SCFM)
- Field data has shown a typical power gen system can produce 300 KW of power from 100 CFM of gas at typical efficiencies (Bevington, 2013).
- Electric Generation - Therefore a system that produces 555 CFM will produce (550/100 CFM or a 5.5 x factor) or 5.5 x 300KW or 1.65 Megawatts of electricity.
- Vehicle Fuel - The same 555 SCFM of biogas = 800,000 cubic feet per day. Assuming 550 BTU in each cubic foot gives 440 Million BTU/day which also = 3140 GGE or gallon of gas equivalent (assuming 140,000 btu per gallon) of vehicle fuel.
- In summary, one can get either 3140 gallons equivalent of vehicle fuel or 1.6 MW of electricity daily from 40,000 tons per year of food waste in this case. The decision of which to produce would depend on local economics. If, for example, the value of electricity was 8 cents per kilowatt-hour the value of this electricity would be $3168 per day. If in this case vehicle fuel was valued at about $2 per gallon the value of this fuel would be about $6280 per day. It is also worth noting that the vehicle fuel scenario incurs extra scrubbing costs, gas compression and extra digester heating costs compared to the electricity scenario.

1.5 SUBSTRATES AND FEEDSTOCKS

Just as in the human body, anaerobic digesters are best fed a variety of substrates for a proper balanced "diet." This mix can provide a balanced, buffered feed which makes a digester less prone to upset. Digesters function well with a baseload substrate like municipal biosolids, animal manure or energy crops as they promote process stability. High energy feedstocks like fats and oils are typically a minority of the feed load due to process stability and buffering concerns.

References:

CalRecylcle http://www.calrecycle.ca.gov/Publications/Documents/Organics%5C2008011.pdf page 52, Swedish Handbook http://www.avfallsverige.se/fileadmin/uploads/Rapporter/Utveckling/U2009-14.pdf Page 31 translated from Swedish by Google Translate. Substrate Handbook for Biogas Production, 2009, Gloversville Johnstown JWTP, 2013, Data from George Bevington, Operations Manager.

2. TYPES OF DIGESTERS

There are many configurations of anaerobic digesters and can run at different target temperatures the most common of which are Mesophillic (95 F, 35 C) or Thermophilic (125 F, 50C). There are different populations of anaerobic microbes that thrive in these temperature zones. Digesters can combine all the main process chemistry steps (hydrolysis, acidification, acetogenisis, methanogenis) either in a single process reactor tank or in two separated reactor tanks. While separation of digestion phases allows for some additional process control, it incurs additional capital costs for the additional tanks and monitoring.

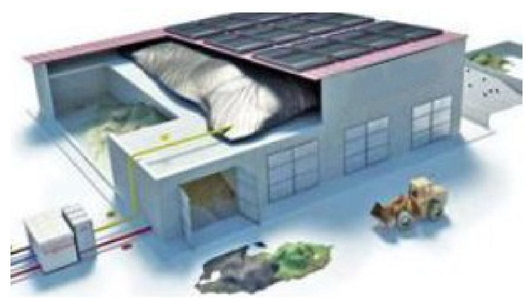
2.1 WET DIGESTERS

The most common digester style is called a "Wet Digester.” They are known as "wet" due to all the substrates being able to be moved around as liquid slurries and mixed by pumps. The consistency of these digesters contents is usually 3-15% total solids. Typical retention times range from 20-40 days. Farm based digesters also come in lagoon or in-ground plug flow reactors. A newer digester style is an Anaerobic Membrane Bioreactor (AnMBR) that uses a membrane filter at the back end of the facility to separate reactor slurry solids from the digestate liquids and hold solids in the system. Yet another system is a multi-phased digester with hydrolysis step and a methanogenesis step, sometimes with interstage solids separation of inert solids, which can allow for optimized residence time.

Wet Style Digester

2.2 DRY DIGESTERS

Dry digesters keep the substrates in a stackable form and remain in a pile during the digestion process. Food waste is mixed with green wastes such as yard debris for structure and porosity and is put into a long, rectangular vessel in a stack. The vessel is then sealed tight and warmed. Warm water, or percolate, is sprayed over the waste stack, collected and recycled. The percolate is biologically active which accelerates the digestion process. Percolate is sent to a separate methanization digester tank where the biogas is generated and the percolate recycled. There are also vertical down-flow reactor configurations where waste is fed in the top and allowed to flow out the bottom a number of days later while digesting along the way.



Dry Digester System

Front Door of Dry Digester Emptying Contents from Dry Digester

Dry Digester Opened Doors

3. SETTINGS FOR DIGESTERS

3.1 MUNICIPAL WASTEWATER TREATMENT FACILITIES

Municipal treatment facilities commonly operate anaerobic digesters to convert the bulk of the volatile solids in their sludges to a form that is more stable, has less volume, easier to dewater and reduced pathogens. Some municipalities have additional available treatment volume and can take in outside substrates to gain tipping fees and increase energy production. Common outside wastes taken by municipal treatment plants include food scraps, cheese and yogurt whey, beverage wastes, fats, oils & grease (FOG) from sources like restaurant grease traps.

3.2 FARM BASED UNITS

Farmers have seen that anaerobic digestion can be an effective way to deal with dairy, swine and poultry manures. The typical cow generates 20 gallons of manure each day. A large 2000 head dairy farm, for example, can generate sizable quantities of manure. Digesters are able to reduce manure odors, convert organic matter to energy, reduce pathogens, return solid bedding materials to the barns and convert the nutrients from manure into more usable form. Farmers are also realizing revenue opportunities in receiving outside feedstocks to feed into their digester to increase gas yield. One thing for farms to be mindful of, however, are the additional nutrients found in these outside substrates, as they will require proper management out the back end of the digester.

Centrifuge at Dairy Digest Happy Farm Digester User

3.3 MERCHANT FACILITIES

A number of merchant digestion facilities have started up in recent years that take in food scraps as their predominant feedstock. These are materials that would usually otherwise have been landfilled or composted. Sending this material first to AD gives it a chance to supply renewable energy, odor reduction and waste stabilization on the way to further composting. Other popular substrates to these merchant facilities include brown grease, food industry processing residuals (i.e. dissolved air flotation float), and wastewater treatment residuals.

Large Urban Merchant Facility

3.4 INDUSTRIAL - HIGH STRENGTH WASTES

Many food and beverage industries commonly have an anaerobic treatment system in the back of their facility. For example, most breweries have anaerobic digesters. Many big protein processors will incorporate large anaerobic lagoons into their operations with long detention times to achieve breakdown of protein-laden wastes.

3.5 COMMERCIAL / INSTITUTIONAL

Large institutions such as universities, resorts and others can install their own anaerobic digestion systems. AD can help drive these institutions to help meet their Climate Action plans and make them more carbon neutral and more sustainable. Often several campus utility vehicles can be fueled by installing one's own digester and converting food scraps to vehicle fuel. These can be great education opportunities for area students, are useful community showpieces and generate compost for local use. A good sized institutional digester can routinely generate the equivalent of 100-200 gallons of liquid fuel equivalent to fuel on-site vehicles.

4. DIGESTER TANK DESIGN

4.1 HEATING

Digesters need to be kept warm for proper bacteriological function. Heating coils can be mounted inside the tank itself or placed within concrete tank walls. External heat exchangers can also be used and can include a plate and frame, spiral or shell-in-tube designs. Ideally excess heat is used from the facilities' combined heat and power (CHP) unit to keep the tank warm, year round. Direct steam injection is also done by injecting steam into a recycle loop. For systems without CHP units or other sources of heat, a boiler system may be required for ongoing heat. A heat source should be considered for system startup.

Heating Coils - Internal to Tank (w/mixer)

4.2 MIXING

Good mixing is important for digesters to ensure proper stirring of the tank, suspension of heavier solids and proper contact between the microbes and the waste. Mixing time can vary from continuous to periodic to save on power costs. Various configurations of mixers are widely adopted in digester design and should be considered a major point of focus for the system's long term reliability and mechanical integrity. Over-mixing can be an issue where excess mixing intensity can de-stabilize the microbes and lead to process upset. Some digester projects will incorporate a combination of the following mixing techniques in a given project.

Top Mounted Roof Mixer

4.2.1 MECHANICAL

Mechanical agitation can be done via a vertical shaft hanging from a fixed digester roof or by a side-mounted propeller style mixers penetrating the tank wall. Submersible mechanical mixers can be mounted on rails connected to the interior tank wall that allow for easy removal from the basin for maintenance. These mixers can be powered by a motor or by high pressure hydraulics. Another style is a mechanical agitator mixer that is on a short shaft mounted inside the digester basin that spins horizontally with paddles extended from the spinning shaft (as shown).

4.2.2 GAS MIXERS

Gas mixers compress digester biogas and reintroduce the gas back into the tank bottom through long, gas lance pipes where large bubbles agitate tank contents on their way back up to the tank surface.

4.2.3 JET MIXERS

Jet mixers operate by pulling sludge from tank contents and reintroducing the sludge at a high speed back into the tank by use of a motive pump to move the tank's contents, frequently spinning contents in a circular pattern through several jets nozzles.

Horizontal Mixer

4.2.4 VERTICAL LINEAR MIXERS (VLM)

Vertical Linear Mixers operate by pushing and pulling reactor contents up and down at a rapid frequency via a flat disk located deep inside the tank held firm by a vertical shaft which is moved by a drive located at the top of the tank. This offers the benefit of keeping all wear parts out of the digester tank.

Precast Panels in Place to Form 26 ft. tall Digester Tank

4.3 TANKS

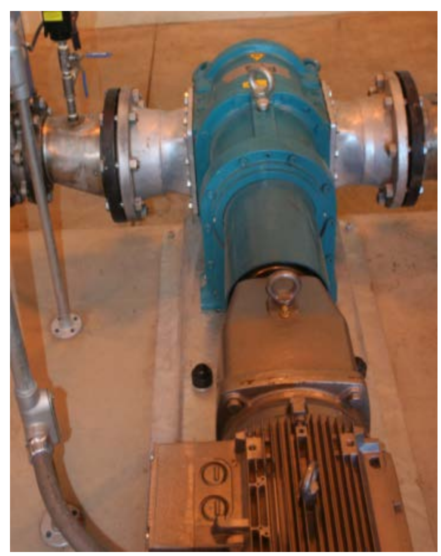
Concrete is commonly used for digester tanks. Poured concrete can be formed in a cylindrical tank shape or an egg tank shape using a network of forms that shape the concrete and hold it in place for proper curing. Precast concrete panels that are formed at an off-site factory can also be shipped by truck to the project site where they are tipped up vertically and then tied together with a network of horizontal cable ties (see picture). Concrete tanks will sometimes have a coating applied to the tank inner wall especially in the corrosive gas/water interface zone to ensure long term durability.

Steel is also commonly used for digester tanks as well. Steel tanks can be erected either as bolted together panels or as welded steel panels. Steel can either stainless steel or be coated with an epoxy paint system or with a glass-fused-to-steel coating. Material selection is key to ensure long term durability and resistance to acid corrosion. Tanks are attached to the concrete foundation by means of an embedded ring cast into the tank foundation. Access hatches are installed for access to the tank interior.

Digester tanks are commonly insulated with either spray-on foam or rigid foam that is attached to the exterior tank surface. Subsequent metal cladding, brick veneer, split block or other materials often attached to the foam's exterior for durability and aesthetics.

4.4 CONVEYANCE (PUMPING)

Various types of pumps are successfully deployed at digester sites. Progressive cavity pumps move very high solids streams using an internal impeller that looks like a corkscrew and rotates in a way that pushes product along through process piping. Piston style pumps move in a linear motion as an engine piston to convey very high solids streams. Rotary lobe pumps utilize rubber or stainless steel lobes that spin in a way that push against themselves and forces high solids material forward. Chopper and grinder pumps are used in waste pits where significant trash and grit can accumulate and can be tough to convey. Centrifugal pumps use a spinning impeller to move material and are useful for liquid aqueous streams. Piping must be sized large enough to prevent plugging.



Lobe Pump Used for Slurries

4.5 ROOFS & COVERS

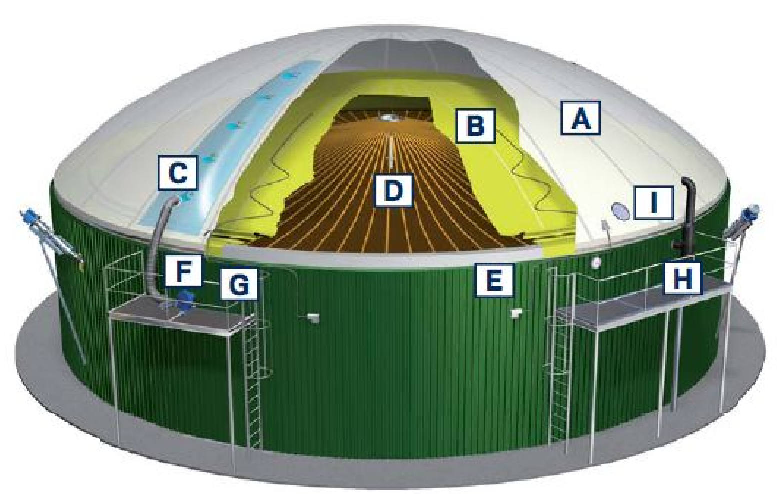
4.5.1 FIXED & FLOATING

Many municipal digesters will commonly have a hard fastened roof on their digesters with mixers hard mounted on the rooftop. Another common digester roof, again found mostly in municipal settings is a metal roof structure that floats on the digester contents and rides vertically on steel guide members and roller mechanisms.

Dual Membrane Cover at Merchant Site

4.5.3 DUAL MEMBRANE

These covers have an outer membrane that spans the tank and is inflated by a blower (see picture) and provides protection from severe weather and odor containment. There is a separate, inner membrane that moves based on the quantity of biogas stored under the outer cover as shown in the cutaway picture.



Cutaway Sketch of Complete Mix Digester showing layering of membrane covers

4.5.4 GAS BLADDER HOLDERS

A soft double membrane inflatable cover that is mounted at grade and holds enough gas volume to buffer swings in demand (see picture). The outer membrane is inflated by an air compressor while the inner layer holds the biogas. Inner pressure settings can be adjusted to user's gas pressure requirements.

Domed Gas Holder

4.6 PROCESS CONTROL

A stable digester can bring years of steady performance. Unstable digesters, on the other hand, that have been overstressed can lose their process biology and gas yield can suffer. Two common tests that an operator generally runs on the digester contents are VFA (Volatile Fatty Acids) and Alkalinity. These tests are simple to run on the lab bench and the ratio of the two parameters to each other show if the system is running in balance or is upset much like a person might experience as an upset stomach reflecting too much digestive acids. Wastes that are deficient in alkalinity may require supplementation via the addition of lime or caustic soda to buffer against the acids generated in the process.

4.7 PRETREATMENT

4.7.1 PASTEURIZATION

A mandatory feature for many digesters in Europe, pasteurization is only now starting to take hold at some US facilities. Pasteurizers will commonly heat batch volumes of feedstocks to roughly 70C for an hour to achieve virus and pathogen kill. They commonly run as several parallel batch heating tanks. In other places, pasteurization is accomplished at 50C for 24 hours.

Batch Pasteurizers in Parallel Operation

4.7.2 FOOD WASTE PROCESSING

Food waste commonly needs to be ground up into a liquid pulp before being fed to the digester to expedite the digestion process. Grinding is commonly done in chopper pumps, macerators, hammermills, and hydropulpers. Each of these works like a big blender. Grit can be controlled with hydrocyclones that spin grit out of suspension. Depackaging technology is used in settings where damaged or expired packaged food is a feedstock and works by first slicing or breaking open the package, spinning out product contents and rejecting the package material into a separate rejects bin. Post-consumer food waste (green bin) is notorious for having contamination which often needs to be pulled out ahead of the digester

4.7.3 MUNICIPAL

Advanced pretreatment systems are gaining popularity that break open cells in waste sludges to assist in getting the AD process started. Thermal hydrolysis and cell lysing systems that use microwaves, electrical currents, and mechanical shearing are beginning to show value.

5. DIGESTATE MANAGEMENT

The resulting liquid from a digester contains dissolved organic matter, fibrous material, and nutrients. Digester operations that have ample land nearby that can apply this fertilizer seasonally to crop lands that are looking for nutrients. Fertilizers derived from AD system can provide results that are equal to or better than comparable synthetic fertilizers. The form of nutrients in digestate is readily plant available. Nitrogen is present as mostly dissolved ammonia, phosphorous as phosphate and potassium in the ionic form. Furthermore, the fertilizers add hums and microbes to the soils improving plant productivity.

Screw Press at Dairy

Many farm based digesters have sizable storage volume to hold this nutrient rich liquid until their crops call for fertilizer. Digestate can be further processed as outlined below based on particular site needs.

5.1 DEWATERING

Liquid digestate commonly leaves a digester with roughly 2-10% Total Solids and thus 90-98%% water. Common devices used to squeeze the water out of these solids are screw presses, belt presses and centrifuges. Screw presses press the solids laden feed liquid against a firm plate which squeezes the liquid out from the digestate. Belt presses utilize permeable belts that sandwich the solids between rollers that squeeze the water from the solids. Centrifuges have a spinning bowl at the heart of the process which, through centrifugal action builds a sludge cake on the inner surface of the bowl as material flows through with relatively clean water emerging at the outlet. These technologies generate a solid digestate material that is about 15-30% solids and 70%-85% water. Fiber and cellulose in the incoming feed can help make for a better quality solid digestate product out the back end. An operating cost to be mindful of is polymer chemicals that are deployed as dewatering aids.

Centrifuge at Dairy Digest Happy Farm Digester User

An analysis from a Midwestern US food waste digester showed raw liquid digestate constituents of 6.8% total solids, 7.1% Ammonia nitrogen, 0.8% total phosphorous, 0.8% total potassium, as an example.

5.2 DRYING & PELLETIZING

For those applications, looking for a very dry solid product a thermal drying step can be used. Systems like paddle dryers, direct fired dryers or infrared dryers can generate a solid fertilizer of greater than 95% solid matter. Pelletizers add an additional amount of solid particle recovery control generating a hard, nutrient dense, dry fertilizer. Ideally, there would be enough waste heat at the site to drive the dryers and avoid purchased gas for drying purposes.

Solid Digestate

5.3 MANAGEMENT OF LIQUID FRACTION

The liquid fraction of dewatered digestate presents both opportunities and challenges. The ideal scenario is for liquid digestates to be simply land applied. In those instances where logistics prevent direct land application, other options need to be evaluated such as discharge to the local sewer (POTW) or to treat the water to stream discharge limits. Digestates can have nitrogen and phosphorous levels that are considered elevated for discharge. Technologies for addressing elevated nutrients in liquid fraction of digestates include:

5.3.1 ANAMMOX

A biological process that converts dissolved ammonia to nitrogen gas utilizing a specialized bacteria. Most applicable where nitrogen levels are over 500 mg/l. Achieves about 85% efficiency.

5.3.2 MEMBRANE FILTRATION

Common membrane filters include ultrafiltration which removes suspended solids and longer molecules and reverse osmosis which filters out virtually all molecules and ions from solution and allows only water to pass through. All membrane filters have a reject stream that requires management, has significant electrical demand to drive the high pressure pumps and periodic membrane cleaning and replacement. Membrane bioreactors (MBR) can be deployed to biologically treat the nutrients.

5.3.3 EVAPORATION

Using excess facility heat to drive an evaporator can be an effective way to reduce the volume of digestate and concentrate the nutrients. Common evaporator types include scraped surface designs where a mechanical scraper is used to keep material from caking onto the hot surfaces.

5.3.4 AIR STRIPPING

Ammonia can be stripped out of solution using stripping technology as it is often easily volatilized depending on its ionic state. This is deployed usually in a tall, packed-tower design. Increasing pH of the digestate, warming the water and pulling a vacuum on the water all enhance the system efficiency. Commonly stripped gasses will be scrubbed with a chemical such as sulfuric acid so as to make a beneficial precipitate like ammonium sulfate fertilizer.

5.4.5 STRUVITE PRECIPITATION

Excess phosphorous in combination with magnesium and ammonium in the digestate can precipitate with high efficiency. A molecular matrix molecule known as struvite forms in the presence of a 1:1:1 ratio of magnesium, nitrogen and phosphorous in the liquid. Struvite crystals can be stored, bagged and shipped to users in need of the phosphorous. Struvite can pose operational issues if allowed to build up in digester piping in an uncontrolled fashion.

Struvite Fertilizer from Digestate

5.4 MANAGEMENT OF FINAL COMPOST

For some uses, solid digestate can be stable enough for immediate use. In other instances, the material is still biologically active and can benefit from additional composting or curing. Solid digestate compost can have beneficial plant fertilizer properties as it is loaded with organic matter and high quality nutrients.

6. GAS UPGRADING & HANDLING

6.1 HYDROGEN SULFIDE H_2S

Biological H2S Scrubber

Hydrogen sulfide is found in all biogas streams to a varying degree based on the type of feedstocks. Depending on the application, H_2S levels can range from under 100 ppm to over several thousand ppm. Due to its corrosive and odorous properties, removing the H_2S is generally a requirement. Additionally, chemicals based on iron salt chemistry, such as Ferric (or ferrous) Chloride, ferric hydroxide or iron oxide can be added to digesters where the iron will stabilize (oxidize) the sulfur in the sludge.

Alternatively, Iron Sponge filters use an iron based media, often iron impregnated wood chips, that oxidizes the iron to a type of rust particle and requires periodic chemical regeneration (see picture). Biological treatment scrubbers utilize a specialized aerobic bacteria (Thiobacillus) that is applied in an upflow packed tower configuration (see picture). The biology reacts with the sulfur in the biogas to form low pH sulfuric acid which can add beneficial sulfur to final digestate upon blending.

Iron Sponge Filters

Water wash systems utilize a high pressure water scrubbing concept which will dissolves the H_2S into the liquid stream. There are also processes that use proprietary iron oxide granular media or activated carbon media as an adsorbent that are effective at removing H_2S. An additional approach is to manage the H2S inside the digester. As shown in the photograph below this digester has wooden beams in the gas head space that exhibit properties favorable to the growth of a bacteria that will oxidize the H2S right in the reactor. Oxidized sulfur will periodically fall back down into the tank contents. Other suppliers will furnish a fabric netting in the gas head space that achieves a similar result. A small percentage of oxygen is sometimes injected in the digester head space to oxidize H2S but must be controlled to <1% oxygen levels for safety purposes.

Concrete Digester tank showing Wood Planks for Desulfurization, Epoxy Paint for Corrosion Resistance, Center Pier Structure and Submersible Mixers

6.2 SILOXANES

Siloxanes are a class of compounds used in cosmetics and other personal care products. They often find their way into digesters and biogas at municipal WWTP and landfill settings. Proper removal by carbon filtration or specialized adsorbents is critical to avoid formation of silica scale on hot surfaces in downstream energy generation (see picture). Once formed, this silica scale can be extremely difficult to remove. Fine silica can cause premature wear and erosion of turbine or engine components leading to failure.

Siloxane Filters

6.3 HUMIDITY

Digester gas is saturated with water vapor. This can cause rusting and corrosion in gas piping and create problems with downstream combustion equipment. As the gas cools, its vapor forms liquid condensate which can pool in low spots and can plug improperly designed piping. Creating condensate either via refrigeration, desiccant drying or through a series of knock-out pots can bring the dew point of the gas down to manageable levels. Condensate management through properly designed piping and dehumidification will prevent a number of possible operational problems. Furthermore, gas piping needs to accommodate and remove possible digester foam that can occur during process upsets. Simply running biogas piping underground in northern climates can be very effective at knocking out moisture.

6.4 CO2

Biogas commonly has 30-50% CO_2. Some downstream applications such as vehicle fuel or gas pipeline injection require reducing that concentration to <2% CO_2. There is a wide variety of commonly deployed approaches to this objective.

6.4.1 MEMBRANES

In a membrane filter system, pretreated gas is compressed and fed into a network of fibers that are about the width of a human hair and packed into a vessel with many thousands of such strands. Due to their ionic properties, methane molecules are rejected by the membrane and the CO_2 filters through the membrane. This allows for both a purified CO_2 and purified methane stream to be produced.

Amine Scrubber

6.4.2 AMINES

These scrubbers incorporate a chemical reaction between the CO_2 and a class of nitrogen based compounds called amines to cleanse the gas. During the process, the amine reaction first selectively scrubs out the CO_2 and shortly thereafter the process is reversed and the CO_2 is vented and the liquid amine chemicals are reused.

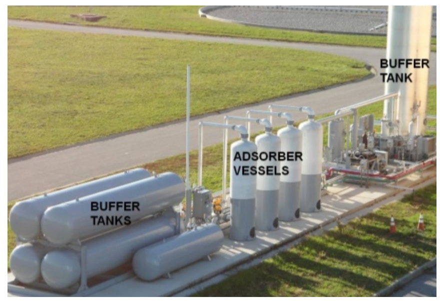
6.4.3 WATER WASH

Water Wash technology incorporates chemical concepts commonly found in making carbonated soft drinks. CO_2 does not dissolve well in water at ambient pressures but will dissolve in water at an elevated pressure. Just as CO_2 degasses out of a carbonated soft drink after the pressure is released by opening the package the same happens in a water wash scrubber where biogas is scrubbed in a pressurized water spray and later released from solution after subsequent depressurization.

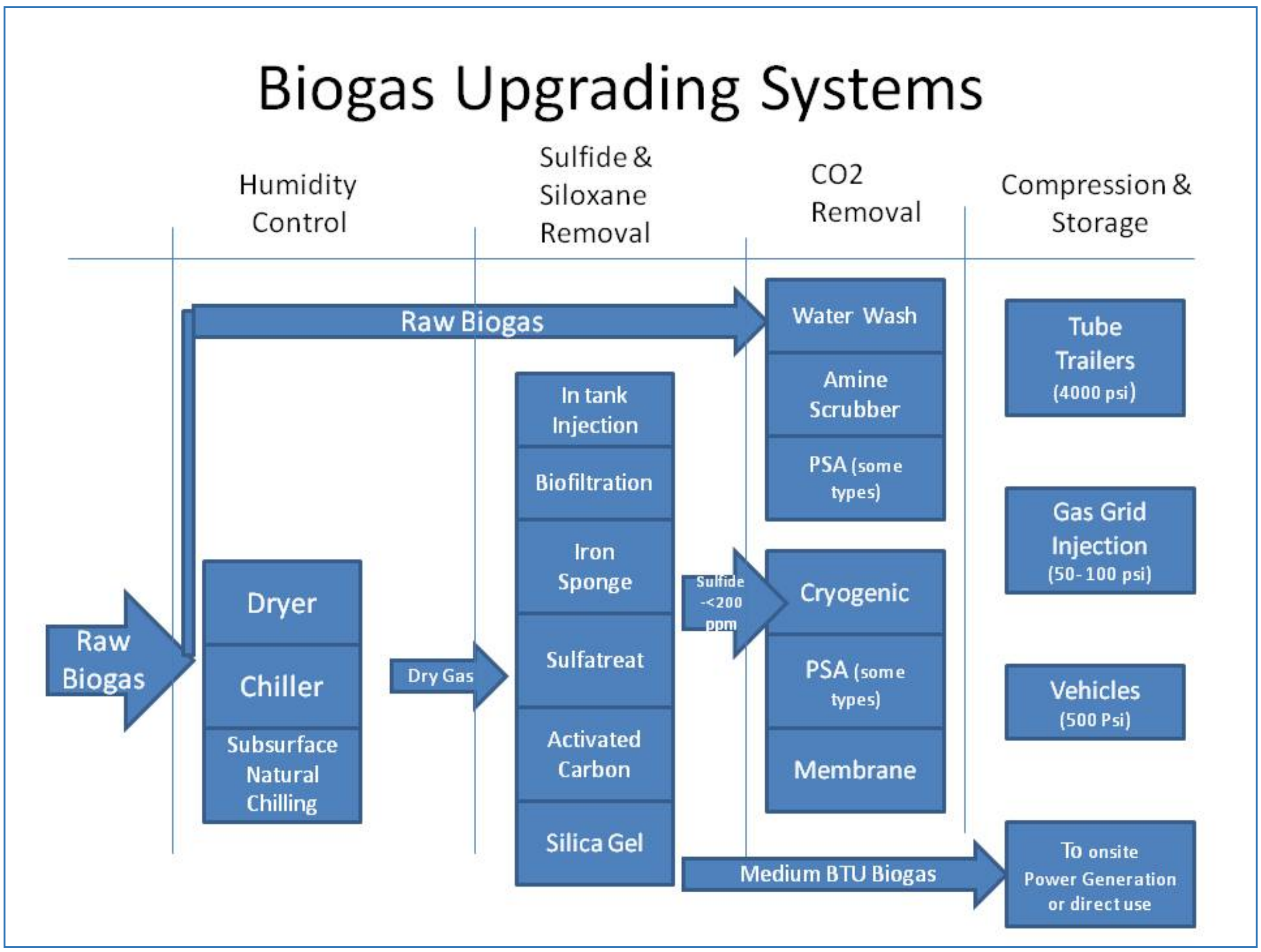

Water Wash System

6.4.4 PSA

Pressure Swing Adsorption technology extracts CO_2 from biogas using a special adsorbent media and allows methane to pass through. Much like a charcoal filter, PSA systems operate several vessels in parallel where at any given time one will be filtering the gas and the others will be regeneration done by backpulsing the beds with air to strip out the adsorbed CO_2. End purity of 98%+ methane is commonly achievable.



700 CFM PSA Unit on Digester Gas



7. GAS USE

7.1 CHP

Combined heat and power (CHP) is the most prevalent means of utilizing biogas. These units use engines similar to those used in cars and trucks where pistons pressurize the gas, combust it and turn a shaft which, in turn, spins a generator. A hard-shell jacket surrounds the exterior of the engine that uses a heat transfer fluid like water or glycol to capture the heat that comes from the combustion happening in the engine. Depending on the quality of the gas, regular oil changes are a regular, significant, maintenance expense. A rule of thumb is that about 100 cubic feet per minute of biogas can drive a 300-Kilowatt engine which is enough power for about 300 homes (reference - Operating data from Gloversville Johnston, NY). Connecting the electricity to the electrical grid can help local utilities meet their Renewable Portfolio Standards (RPS). The connection from digester to power grid can sometimes be a complex process, as Utilities tend to closely scrutinize projects that provide power onto their grid for ensuring grid integrity.

500 KW CHP Engine

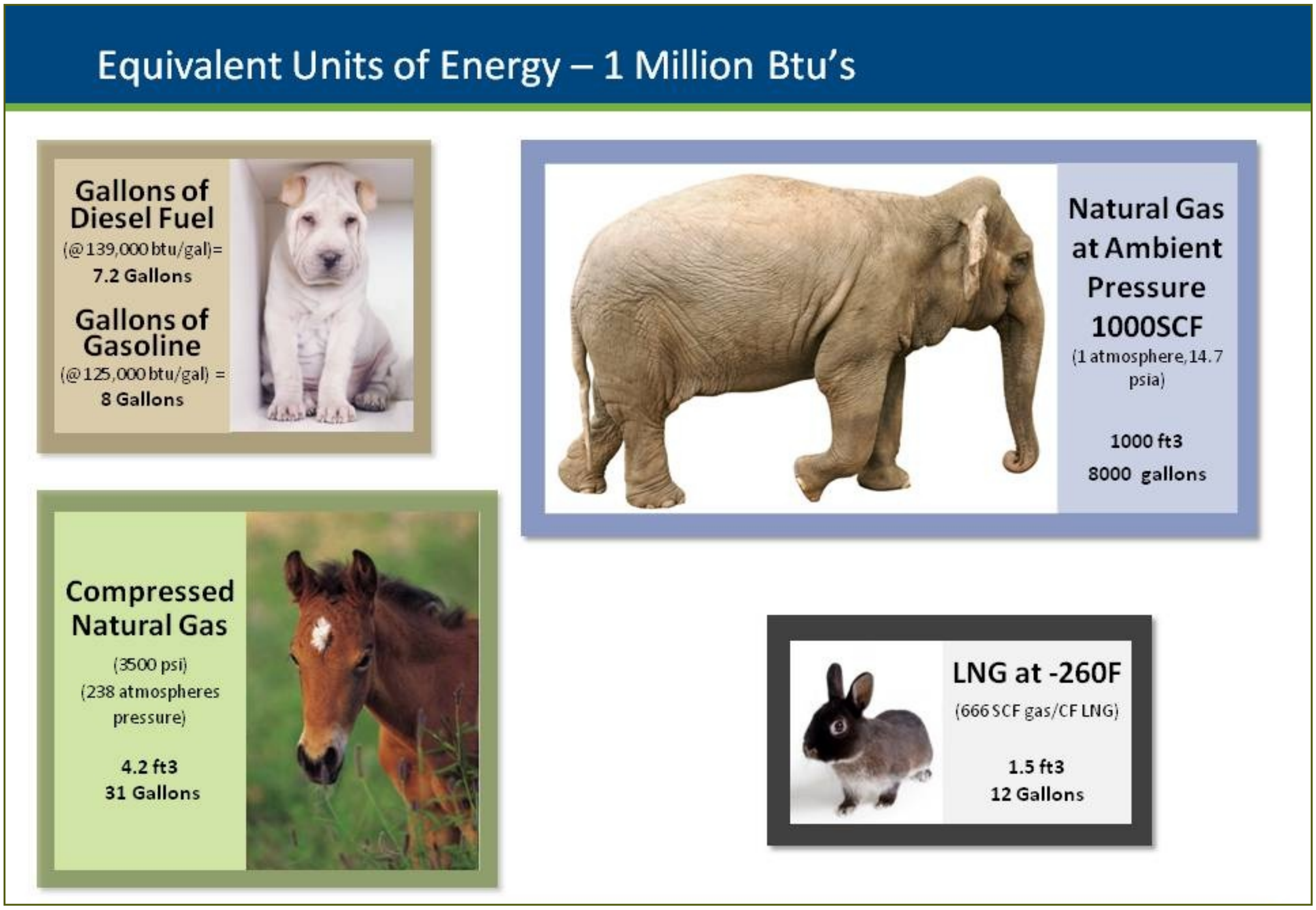
7.2 OTHER - MICROTURBINES & FUEL CELLS

These units require a higher feed pressure and higher feed gas quality than CHP engines but can provide decades of reliable service and very high conversion efficiency.

7.3 VEHICLE FUEL

Once the gas has been upgraded and the CO_2 removed, it is ready to be compressed and used in vehicles. Compressed Natural Gas (CNG) is routinely compressed to 2500 psi in high pressure cylinders to store the gas. Compressing the gas reduces the volume by a factor of 200 vs atmospheric gas. Upgraded biogas has about 950 Btu of energy in every cubic foot of gas. Diesel fuel, on the other hand has about 140,000 Btu in a gallon. Gas units are commonly referred to in units of GGE or Gallons of Gas Equivalent for vehicle fuel projects. For example, the energy in 1000 cubic feet of upgraded biogas equals about 7.2 Gallon of Gas Equivalent (GGE) as each of these units has about 1 Million Btu's of energy. The illustration below compares how the equivalent amount of energy varies by volume in different gas forms and pressures.

High Pressure Bio CNG Trailer for Vehicle Fueling



Biogas used in vehicle fuels can be considered an "Advanced Biofuel" as spelled out in the Renewable Fuel Standard (RFS2). This is monetized by selling credits that are tracked by Renewable Identification Numbers (RIN). Biogas is considered the lowest carbon intensity fuel and can qualify for California's Low Carbon Fuel Standard.

7.4 DIRECT CONNECTION TO GAS GRID

Upgraded biogas can also be injected into the natural gas utility grid as long as local regulations allow and the grid is in close enough in geographical proximity. Currently there are no national standards for upgraded biomethane, so target gas quality and injection pressure is a locally driven issue dependent on pipeline operator. Common specifications to connect to the grid will be Methane, Oxygen, Nitrogen, CO_2 levels and dew point. An interconnect agreement has to be secured with the local pipeline in order to connect to the grid. Once the facility is connected to the grid, the gas can be sold to any user that uses natural gas from the grid.


Gas Safety Device

7.5 GAS SAFETY

Gas safety equipment must allow a digester to vent gas should system pressure elevate. Vented gas should be sent to a flare. Pressure relief valves must be properly designed, insulated and heated to ensure proper year round operation. Burst discs, foam traps and flame arrestors round out the safety equipment needed.

8. PROJECT DEVELOPMENT AND FINANCE

Securing financing for a digester project can be challenging and takes significant time and effort. Each project progresses based on its individual merits of owner's personal or corporate equity position, credit record, management resume and the projected financial payback for investors. Often grants such as the USDA REAP grant, and other Federal and State grants are an integral part of the financial backbone of a project. AD projects can also obtain a number of tax credits that can be of great value to businesses that have tax burdens. AD projects can involve a complex web of securing the site, site permits, feedstock input agreements, Power Purchase Agreements (PPA), off take agreements for fertilizer byproducts, equity financing, debt financing, construction period financing, selection of the operations and maintenance crew and grant funding. The number of moving parts to a successful AD project deal going forward can be daunting but generally makes for a great story when all the parts fall into place.

Public Private Partnerships (P3) are gaining in popularity whereby private companies can bring financing to project at municipal settings in exchange for a long term partnership.

9. DIGESTER CONSTRUCTION METHODOLOGY

There are a wide number of ways to contract to build a digester project. Some projects will follow an EPC path (Engineer/Procure/Construct). In the EPC case the owner deals with one single entity for all issues pertaining to system design, process performance and construction. An EPC provider will often bring in a digester process provider onto their team for a system performance guarantee. Early stage project geotechnical report and soil borings are required to understand site constructability. Some urban sites require environmental site assessments in case of previous site contamination.

Some owners will chose to split projects into multiple contracts where they will contract separately for system design, permitting, construction and the process and power generation equipment. This can put a heavier management responsibility on the owner but can allow for some additional financial transparency, flexibility and hardware choices. This can provide additional transparency and flexibility at the 30% design stage when system design and costing gets tightened up. A Basis of Design (BOD) report is a common early stage deliverable that includes general arrangement drawings, process flow diagrams, equipment lists, electrical one-line diagrams and process & instrumentation diagrams (P&IDs). At all times local building and construction codes need to be understood and adhered to.

Each of these models provides their own level of flexibility and accountability for all participants involved. Some key points involve payment considerations assumption of process performance risk, schedule risk, site condition risk, power output risk and construction risks.

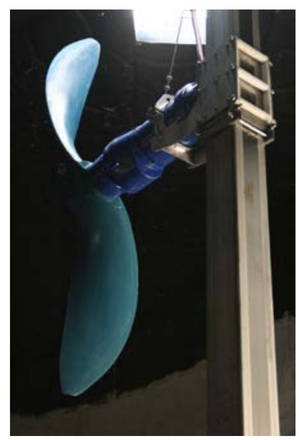
10. FACILITY INSTALLATIONS

Complete Mix Digester Tank Showing Freestanding Mixers, Wooden Desulfurizers and Center Pier Column

CSTR Complete Mix Digester, Inflatable Gas Storage and Containerized CHP Units

Submersible Mixers on a Freestanding Support Structure

Side Mounted Digester Mixer and Tank View Port



Submersible Mixer on Support Pole

Digester with Center Pole Cover Support

Gas Storage Dome Showing Inflation Hose

CDM Smith

11. US PROJECT EXAMPLES

Magic Hat Brewery in S. Burlington, VT

Reduces byproduct management costs by over 60% through cutting waste trucking and municipal surcharges. Reduces odors; truck traffic; BOD and phosphorus loading to the municipal treatment facility. Generates one-third of the brewery's electrical demand while nestled in a residential neighborhood. Digests spent grains and wastewater.

Cayuga County, NY Soil and Water Conservation District

Fed by manure from 1500 cows. Community digester sends heat and electricity to nearby prison and senior housing development. 633KW electrical generation capacity. Hydraulic Digester Technology. Biodesulfurization

$9.7 M total installed cost

Synergy Digester -- Wyoming County, NY

Co-Digests imported food waste and dairy cow manure from 1200 Head Dairy. Makes 1.4 MW of electricity. $7.7 M total Capex. Includes Pasteurization

Lawnhurst Dairy - Stanley, NY

Co-Digests imported food waste and dairy cow manure from 1500 milking cows. Generates 541 KW of electricity. $5M total installed costs

Receives liquid industrial and municipal residual wastes from local community and generates 1.6 MW power. $12M total installed cost. Capacity – 60,000 – 75,000 wet tons per year of wastewater treatment plant residuals (biosolids), Food Processing Wastes, Urban GTW/FOG. Pasteurization for achieving digestate/biosolids “unrestricted use” designation under EPA 503 Class A biosolids. Start-up – Dec 2012

GenEarth – Berkeley County, SC (Charleston area)

Receives preconsumer food waste, grasses. 1.6 MW of electricity. 30,000 tons per year. Entec Technology – Wet Digester CSTR. Design, build, own, operate, and maintain. 100 tons per day or about 30,000 TPY of commercial organics (post consumer food waste), fats/oils/greases, and some agriculture residues (manure and straw).

JC Biomethane - Junction City OR

Cow manure from two large dairy farms conveyed by pipeline. Community digester. $8M installed cost. Three large, complete mix digester tanks.

Clear Horizons - Dane County, WI

Four fermentation vessels (70 ft. x 23 ft. x 17 ft. High), Runs as a "dry" batch process that lasts one month for each cycle. Treats 8000 tons per year of food waste, yard wastes and crop wastes. Biogas fires a 350 KW electrical generator

University of WI - Osh Kosh

Processes 40,000 tons per year of mixed food and yard waste from the Metro Vancouver region (population 2.5 million). The batch two-stage high solids anaerobic digester produces 2.2 MW combined heat-and-power and 15,000 metric tons of high quality compost hat is returned to local farms and landscapes. Virtual tour at harvestpower.com/energygarden


Harvest Energy Garden - Richmond, BC

Co-digests 120,000 tons per year of commercial food waste and biosolids from local theme parks and businesses. The facility produces 6 MW combined heat and power -- enough to power 2,000 Floridian homes -- and 3,200 metric tons per year of granular fertilizer for application on local agriculture.


Harvest Energy Garden - Orlando, FL

Uses low-solids anaerobic digestion to process 70,000 tons per year of commercial food waste, producing 5.6 MW combined heat and power and 5,200 metric tons of granular fertilizer each year.


Harvest Energy Garden - London ON

PSA unit from Guild. 385 cubic feet per minute free rate. Generates pipeline quality gas of 98% methane.

Biogas Upgrading System at GA Lagoon Based Digester

SAMPLE LIST OF SIGNIFICANT MERCHANT FOOD WASTE DIGESTERS IN THE US

Name / Developer	Location	Feed (wet tpy)	Power (KW)/ GGE
Harvest Power	Orlando, FL	120,000	3.2 MW
Novi Energy	Freemont, MI	100,000	3 MW
FCPC Renewable Gen	Milwaukee, WI	100,000	2 MW
Zero Waste (dry system)	San Jose, CA	90,000	1.6 MW
GenEarth	Sumter, SC	70,000	1.6 MW
quasar	Columbus OH	43,000	1.3 MW
JC Biomethane	Eugene, OR	30,000	1.6 MW
Clean World Partners/ U C Davis	Sacramento, CA	20,000	450 GGE vehicle fuel

CDM Smith

12. APPENDIX

TERMINOLOGY:

CSTR	Completely Stirred Tank Reactor. Also known as a "wet" style digester
Feedstocks	Any material including organics mixed wastes that are fed into a digester
Offtaker	An entity that is buying fuels or fertilizer byproducts from a digestion facility.
Post-Consumer Waste	Material collected from food plates from restaurants or cafeterias or home kitchen preparation
Preconsumer Waste	Waste from food factories, grocery retailers
SSO	Source Separated Organics - The system by which organic waste generators such as homes and businesses segregate organic materials from other waste streams at the point of collection.
Substrates	Term used interchangeably with "Feedstock"
Volatile Solids	The fraction of the feed solids that is readily convertible to biogas. The opposite is the nonvolatile or ash fraction.

FREE ANAEROBIC DIGESTION BIOGAS MODELS:

Anaerobic Digestion CREST Model

- Biowatts
- Energy 4 Farms

Additional Resources:

- EPA Agstar
- BioCycle Magazine
- American Biogas Council
- Digester.com - Industry blog and podcast

ABOUT THE AUTHOR

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