Biogas Wastewater Assessment Technology Tool (BioWATT) – User Manual

This user manual contains the following information about BioWATT:

1. Purpose
2. Intended Users
3. BioWATT Structure
4. How to Use BioWATT
5. Brief overview of the wastewater treatment process and descriptions of the four wastewater-to-energy technologies evaluated by BioWATT.

1. Purpose

The purpose of BioWATT is to provide a quick and preliminary assessment of wastewater-to-energy projects.

Based on as little as two inputs provided by the user (average hydraulic load and average inflow BOD_5 concentration), BioWATT provides the following:

- Biogas production estimate for various wastewater-to-energy technologies
- Electricity generation potential from the produced biogas
- Greenhouse gas savings associated with biogas-generated electricity (compared with a situation where no electricity is produced from biogas [i.e., all electricity needed at the plant is purchased at the grid]).
- Preliminary assessment of the wastewater treatment facility's electricity demand that can be met through biogas-generated electricity
- Preliminary design parameters of major components of a wastewater-to-energy project, such as required digester volume, required gas holder volume, and total combined heat and power (CHP) electric power output
- Impact on a wastewater treatment facility's operating expenses (OPEX) by investing in energy generation technology.

BioWATT contains two modules (Basic and Advanced) to accommodate users with differing knowledge of wastewater treatment systems and technologies. The Basic Module requires as little as two user inputs, whereas the Advanced Module can be customized for multiple user inputs for more refined results.

Note: BioWATT is not meant to be used for an investment grade analysis. It is simply meant to provide a preliminary assessment of wastewater-to-energy projects, assisting users to determine if additional analysis is warranted. It should not be used as a substitute for a feasibility study or project design.

2. Intended Users

Intended users for BioWATT include wastewater treatment operators, consultants involved with wastewater project development, and federal/state/local decision makers who want to evaluate the opportunity for methane emission reduction and energy production at wastewater treatment facilities. It is primarily intended to assess projects in developing countries.

3. BioWATT Structure

BioWATT is Microsoft Excel-based, and consists of three worksheets.

1. ***Introduction***
   This worksheet provides instructions for how to use BioWATT.

2. ***Basic Module***
   This worksheet is intended for most users of BioWATT. It consists of two parts:

   - The upper part of the sheet is where the user inserts the necessary input data, reflecting conditions of a specific project. The sheet also contains default values, which can be utilized if project specific input data are not known.
   - The lower part summarizes output results (e.g., biogas production, electricity generation from biogas, greenhouse gas savings, etc.). All output results are calculated in the "Advanced Module" worksheet. Selected values in the "Advanced Module" worksheet are copied into the "SUMMARY OUTPUT RESULTS" section of the "Basic Module" worksheet.

3. ***Advanced Module***
   This worksheet is intended for people with more advanced knowledge of wastewater treatment systems. It allows users to enter specific wastewater and wastewater technology data and overwrite standard defaults included in BioWATT to develop more refined results.

4. How to Use BioWATT

The following are instructions for using BioWATT.

Most users should enter data and view results in the "Basic Module" worksheet. This worksheet uses standard defaults to produce results. Users with more advanced knowledge of wastewater treatment can use the "Advanced Module" worksheet to enter more specific data and/or overwrite defaults included in the tool to develop more refined results.

1. Enter project specific data into the GREEN cells.

   - On the "Basic Module" worksheet, inputs are in the "INPUT DATA" section.
   - On the "Advanced Module" worksheet, more detailed inputs are available across the various wastewater-to-energy technologies evaluated by the tool.

2. View Results

- Summary results for the wastewater-to-energy technologies evaluated are shown in the “Basic Module” worksheet under “SUMMARY OUTPUT RESULTS.” (All output results are calculated in the “Advanced Module” worksheet. Selected values in the “Advanced Module” worksheet are copied into the “SUMMARY OUTPUT RESULTS” section of the “Basic Module” worksheet.) All Outputs in both the "Basic Module" and "Advanced Module" worksheets are in ORANGE cells.
- More detailed results and data related to the wastewater-to-energy technologies evaluated by BioWATT can be seen in the “Advanced Module” worksheet. This is true whether the user relies on the tool’s standard defaults or if the user chooses to enter more specific data and/or overwrite defaults in the “Advanced Module” worksheet.

In both the "Basic Module" and "Advanced Module" worksheets, explanatory comments and/or field instructions are included for selected inputs and outputs.

Users of BioWatt can change all values in GREEN cells. All other cells are locked. However, users are free to unlock the tool to make any desired changes. The delocking key for each worksheet is: W2E.

5. Technologies Evaluated in BioWATT

BioWATT evaluates four wastewater-to-energy technologies:

- Conventional activated sludge (CAS) with anaerobic digester (plus optional co-digestion)
- Trickling filter (TF) with anaerobic digester (plus optional co-digestion)
- Upflow anaerobic sludge blanket (UASB) reactor
- Covered anaerobic pond

The following first provides a brief introduction to wastewater treatment, and then presents an overview of each of the technologies evaluated by BioWATT, including what each is, when to use each, advantages/considerations of each, and technical features and requirements of each.

Introduction to Wastewater Treatment

Wastewater treatment processes are designed to achieve improvements in the quality of the wastewater, and are hence closely related to the standards and/or expectations set for the effluent quality. The various treatment processes may reduce:

- **Suspended solids** (physical particles that can clog rivers or channels as they settle under gravity).
- **Biodegradable organics** (e.g. biochemical oxygen demand [BOD]) which can serve as “food” for microorganisms in the receiving body. Microorganisms combine this matter with oxygen from the water to yield the energy they need to thrive and multiply, thereby depleting the necessary oxygen levels for other aquatic organisms.
- **Pathogenic bacteria** and other disease causing organisms. These are most relevant where the receiving water is used for drinking, or where people would otherwise be in close contact with it.

- **Nutrients**, including nitrogen and phosphorus. In receiving waters these nutrients can lead to strong proliferation of unwanted algae, which can themselves become heavy loads of biodegradable organic load.
- Treatment processes may also neutralize or remove **industrial wastes** and toxic chemicals. This type of treatment should ideally take place at the industrial plant itself, before discharge of their effluent in municipal sewers or water courses.

Widely used terminology refers to three levels of wastewater treatment: primary, secondary, and tertiary (or advanced).

- **Primary (mechanical) treatment** is designed to remove gross, suspended, and floating solids from raw sewage. It may include screening (or sieving) to trap solid objects, degritting, fat removal, and sedimentation by gravity to remove suspended solids. This level is sometimes referred to as "mechanical treatment", although chemicals are sometimes used to accelerate the sedimentation process. Primary treatment without chemicals can reduce the BOD of the incoming wastewater by 20-35% and the total suspended solids by 50-65%. Primary treatment is usually the first stage of wastewater treatment. Many advanced wastewater treatment plants in industrialized countries have started with primary treatment, and have then added other treatment stages as wastewater load has grown, as the need for improved treatment has increased, and as financial resources have become available.

- **Secondary (biological) treatment** removes the dissolved organic matter that escapes primary treatment. This is frequently implemented in **aerobic systems** with supply of artificial aeration (e.g. conventional activated sludge [CAS]) or with natural aeration (e.g. trickling filters). In such systems, boosted by the air supply, microbes consume the organic matter as food, and convert it to carbon dioxide, water, and energy for their own growth and reproduction. The biological process is then followed by additional settling tanks ("secondary sedimentation") to settle and keep the microbes in the treatment system. About 85-95% of the suspended solids and BOD can be removed by a well running plant with secondary treatment.

  Instead of the above described secondary (biological) treatment in aerated systems, sometimes this secondary stage may also be designed as an **anaerobic system** (i.e., one without any artificial aeration or ventilation). In such systems the organic matter is additionally converted into considerable quantities of methane, which may be collected and utilized. Such anaerobic systems are usually followed by a smaller aerobic system to permit for final effluent polishing. Eventually, the same level of treatment can be achieved through such anaerobic-aerobic systems, as with aerobic systems.

- **Tertiary treatment** is any additional treatment beyond secondary. Depending on the applied tertiary technologies, it can remove more than 99 percent of all the impurities from sewage, and can even produce an effluent of drinking-water quality. The related technologies can be very expensive, requiring a high level of technical know-how and well trained treatment plant operators, a steady energy supply, and chemicals and specific equipment which may not be readily available anywhere. An example of a typical tertiary treatment process is the modification of a conventional secondary treatment plant to remove additional phosphorus and nitrogen.

Anaerobic Digestion and Co-digestion

Biodegradable organics (BOD) and excess microbes ("sludge") removed from primary and (aerobic) secondary treatment can be processed in anaerobic sludge digesters. Anaerobic digesters are sealed vessels where microorganisms break down biodegradable material in the absence of oxygen. In addition to eliminating pathogens and reducing odors, one of the end products of anaerobic digestion is biogas, which can be combusted to generate electricity and heat, or can be processed into renewable natural gas and transportation fuels. In addition to the sludge digestion, anaerobic digesters can be designed to accept additional organic waste feedstocks (e.g. fats, oil, greases, restaurant and canteen waste, dairy waste, crop residues, animal manure, etc.). These additional waste streams boost biogas yields, and, depending on the size of the wastewater facility, can be the difference between an economically feasible project and one that is not feasible.

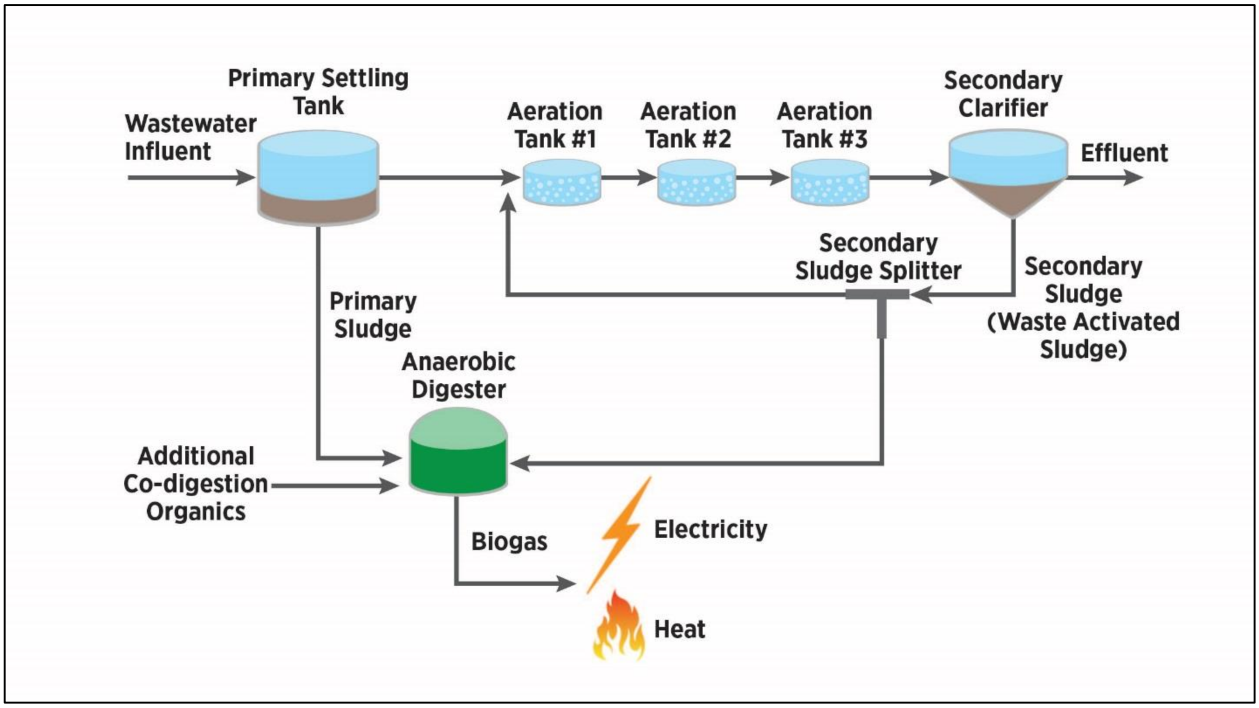
Wastewater-to-Energy Technologies Evaluated by BioWATT

1. Conventional Activated Sludge (CAS) with Anaerobic Digester (Plus Optional Co-digestion)

What is it?

In a typical CAS plant with anaerobic digestion, wastewater influent first goes through a primary settling tank to remove suspended and floating solids. Sludge removed from the primary settling tank (primary sludge) is diverted to the anaerobic digester. After leaving the primary settling tank, the wastewater enters the activated sludge process (secondary treatment). First, the wastewater goes through a series of aeration tanks to remove biodegradable organics. In these tanks, microorganisms cultivated in the treatment process are kept in suspension, aerated, and in contact with the waste they are treating it. The result is a breakdown of organic matter into carbon dioxide, water, and other inorganic compounds. After the aeration tanks, the wastewater is held in a secondary clarifier to settle out any remaining sludge (secondary sludge or waste activated sludge). Some of the secondary sludge is sent to the beginning of the activated sludge process, providing the microorganisms that drive the treatment process, and the rest (excess) is diverted to the anaerobic digester. The anaerobic digester produces biogas from the primary sludge, secondary sludge, and any other organic feedstocks sent to the facility for co-digestion.

Typical Conventional Activated Sludge Plant with Anaerobic Digestion



Source: Global Methane Initiative

When to use it?
CAS is widely used in centralized plants in developed countries. While many activated sludge treatment plants have been built in developing countries, very few work as well as intended. Activated sludge can be appropriate where high removal of organic and nutrient pollution is required, funds and skilled personnel are available for operation and maintenance, and land is scarce or expensive. Since activated sludge requires the continuous operation of air blowers and sludge pumps, a steady energy supply is a key requirement. The system usually needs some form of pretreatment, such as screening and degritting.

Advantages

- Activated sludge is the best documented and most widely used form of secondary wastewater treatment.
- Efficient removal of organic material and nutrients, when designed and professionally operated according to local requirements.
- The process itself has flexibility and numerous modifications that can be tailored to meet specific requirements (e.g. for nitrogen removal).
- Low land requirements.

Considerations

- Expensive in terms of both capital and O&M costs.
- Requires a constant energy supply.
- Needs trained operators who can monitor the system and react to changes immediately, and the availability of spare parts and chemicals may be an obstacle.

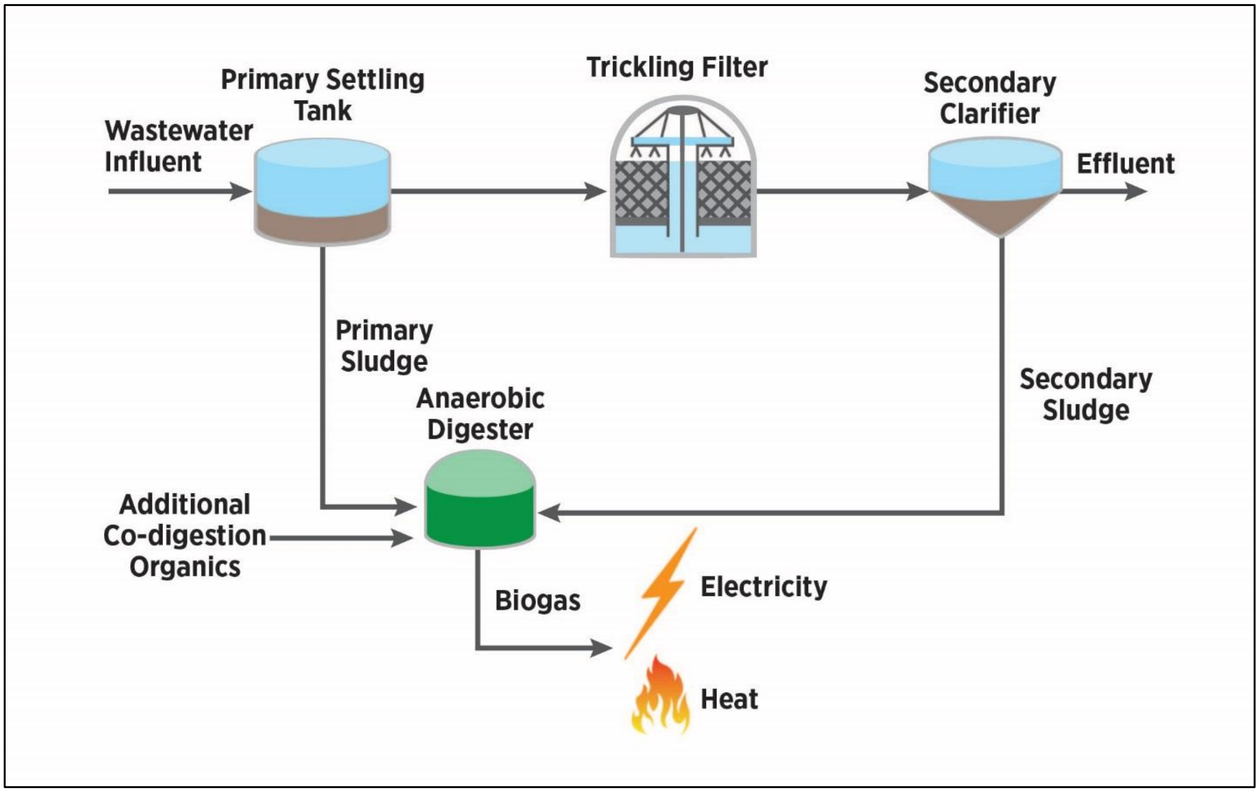
- The track record of activated sludge plants in the developing world is often poor, and few operate as designed or intended.

Technical features and requirements
There is a vast literature on the design of various forms of the activated sludge treatment processes. General considerations include: wastewater characteristics, local environmental conditions (including temperature), possible presence of toxic or other inhibitory substances (will the process receive industrial effluents or septage, for instance), oxygen transfer requirements and reaction kinetics (microbe detention time in the system, related to quality and quantity of wastewater received, effluent requirements, sludge treatment requirements and other factors listed above).

2. Trickling Filter (TF) with Anaerobic Digester (Plus Optional Co-digestion)

What is it?
In the typical wastewater treatment process involving trickling filters and anaerobic digestion, wastewater influent first goes through a primary settling tank to remove suspended and floating solids. Sludge removed from the primary settling tank (primary sludge) is diverted to the anaerobic digester. After leaving the primary settling tank, the wastewater enters the trickling filter (secondary treatment). As with the activated sludge process, trickling filters are used to remove organic matter from wastewater, but rather than pumping air through the wastewater (as is done with conventional activated sludge), trickling filters consist of a bed of a highly permeable medium, nowadays usually made from specifically designed plastics, to which micro-organisms attach. Wastewater is trickled onto the medium from the top using a rotary distributor, while natural ventilation through air convection provides aeration and allows the organic material to degrade. After leaving the trickling filter, wastewater goes to a secondary clarifier to settle out those microbes that have been detached from the media and flushed out (secondary sludge). This secondary sludge is diverted to the anaerobic digester and is digested along with the primary sludge and any other organic feedstocks sent to the facility for co-digestion to produce biogas.

Typical Trickling Filter Plant with Anaerobic Digestion



Source: Global Methane Initiative

When to use it?

Trickling filters are suitable in areas where large tracts of land are not available for land intensive treatment systems. They are appropriate for small, medium, and large sized communities. Unlike conventional activated sludge systems, trickling filters have low power requirements and require only a moderate level of skill and technical expertise to manage and operate.

Advantages

- Simple, reliable, biological process.
- Effective in treating organics and nitrogen.
- Durable.
- Low power requirements.
- Low land requirements.
- Moderate level of skill and technical expertise needed to manage and operate.

Considerations

- Requires regular operator attention. Without due attention and regular filter flushing incidence of clogging can be high due to accumulation of excess biomass.
- Additional treatment may be needed to meet more stringent discharge standards.
- Flexibility and control are limited in comparison with activated-sludge processes.
- Certain risk of filter flies, if the wastewater is not uniformly distributed over the complete filter surface.

Technical features and requirements

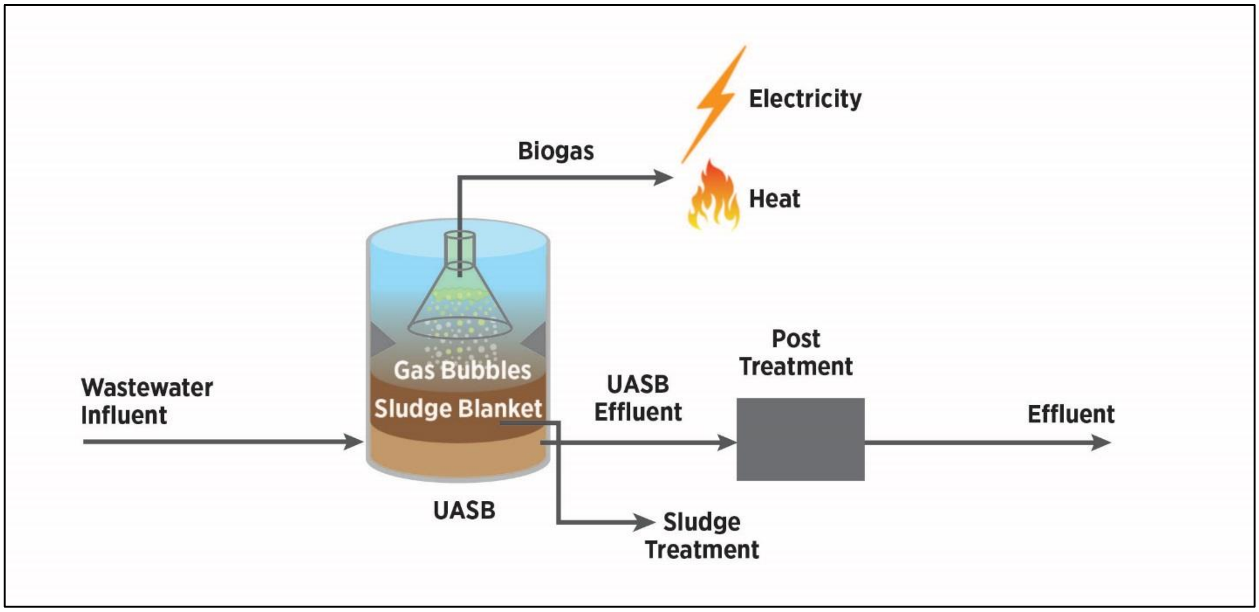
A trickling filter consists of permeable medium made of a bed of plastic media (in former times it also used to be rock or slag), over which wastewater is distributed to trickle through. Packed media beds range in depth from 4.3 to 12.2 meters (14 to 40 feet), and usually provide 100-140 m2/m3 (3.0 – 4.3 sq ft/cu ft) of surface area and > 95% void space. Rock or slag beds have larger diameters and are typically 0.9-2.4 meters (3 to 8 feet) deep with rock size varying from 2.5-10.2 cm (1 to 4 inches). Most rock media provide approximately 40-80 m2/m3 (1.2-2.4 sq ft/cu ft) of surface area and around 40-60 percent void space. It is essential that sufficient air be available for the successful operation of the trickling filter. It has been found that to supply air to the system, natural draft and wind forces are usually sufficient if large enough ventilation ports are provided at the bottom of the filter and the medium has enough void area.

3. Upflow Anaerobic Sludge Blanket (UASB) Reactors

What is it?

An upflow anaerobic sludge blanket (UASB) reactor is a form of anaerobic digester. With UASBs the process of sludge settlement and digestion occurs in one or more large tanks, making UASBs essentially a combination primary/secondary treatment process. Only the post UASB liquids, which have much reduced organic content, need to be aerated and/or treated to remove pathogens. In UASBs wastewater is pumped upwards through a ‘blanket’ of granular sludge which treats the wastewater. Bacteria living in the sludge break down organic matter by anaerobic digestion, producing biogas which can be captured at the top of the reactor. The upward hydraulic flow works in conjunction with gravity settling to suspend the sludge granules until they reach a threshold density and fall to the bottom of the reactor as a ‘sludge bed,’ which is then treated.

Typical UASB Plant



Source: Global Methane Initiative

When to use it?

UASBs are best suited for regions that have warm climates throughout the year. A typical minimum threshold wastewater temperature is about 18-20°C. UASBs are not appropriate for cold climates, and for small or rural communities without skilled labor. They are particularly adapted for densely populated urban areas as they have low land requirements.

Advantages

- Can treat high organic loads in fairly short hydraulic retention times.
- Typical efficiency of about 60-70% BOD removal.
- Does not require expensive aerating system.
- Low land requirements (can be constructed underground).
- Lower energy demands than conventional activated sludge.
- The excess sludge from subsequent posttreatment can also be digested in the UASB.
- Low sludge production.

Considerations

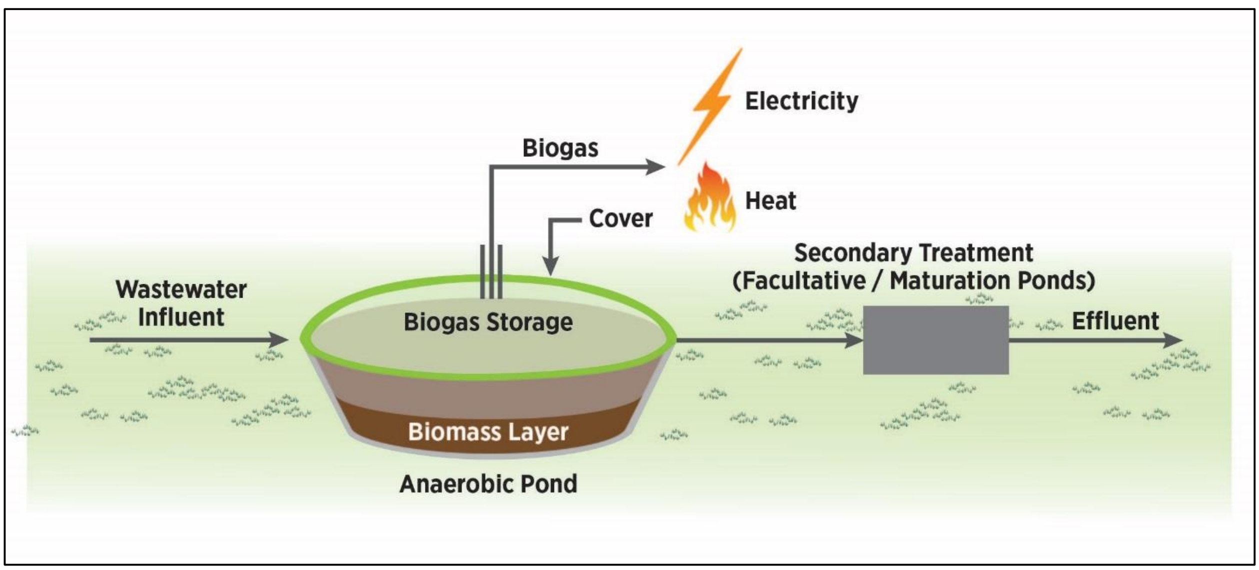
- Somewhat slower start-up than CAS, since anaerobic sludge yield is lower than aerobic sludge yield; hence it takes more time until sufficient biomass for proper treatment has built up.
- Efficient preliminary treatment is imperative (efficient screening, or better sieving) to minimize scum accumulation under the biogas collector.
- A skilled operator is required to monitor the reactor, repair parts, and ensure that excess sludge is removed, and biogas is properly collected.
- Cheaper in construction and maintenance compared to conventional aerobic processes.
- Requires corrosion resistant materials.
- Not all parts and materials may be locally available.

Technical features and requirements
UASB reactors are typically constructed out of concrete and are circular or rectangular in shape. However, the rectangular type is by far the most widespread shape nowadays. The corrosive environment makes it imperative that all installations are made from noncorrosive materials, such as PE, PVC or GRP. Typical water depth in UASB equals 3-6 m, and individual reactors usually have a volume < 3000 m3 at large WWTPs. Critical elements for the design of UASB reactors are the influent distribution system, the gas-solids separator, and the effluent withdrawal design. The gas that rises to the top is collected in a gas collection dome. To ensure the reactor is well-mixed and allows the formation of granules for a good contact of the active sludge blanket and the influent sewage, it is critical that the influent is equally distributed over the bottom before moving upwards. Further, it is advisable to install sludge sampling and discharge pipes at different levels of the reactor.

4. Covered Anaerobic Pond

What is it?
Anaerobic ponds are basins in which wastewater is treated under the absence of oxygen. Wastewater influent flows directly into the anaerobic pond after screening and degritting. Solids settle to the bottom of the pond, where they are digested. Typically, anaerobic ponds are open, but when covered, biogas can be captured and used for beneficial purposes (e.g., for the generation of electricity and heat). Anaerobic ponds are a primary treatment process, but secondary treatment can be added with facultative and maturation ponds, with trickling filters, with CAS, or with other aerobic technologies.

Typical Covered Anaerobic Pond



Source: Global Methane Initiative

When to use it?
Anaerobic ponds are best suited for small and medium-sized communities. They are inexpensive to build and operate, and are a quick and easy method of wastewater treatment.

Advantages

- Simple and robust.

- Typical efficiency of about 50% BOD removal and 60-80 % suspended solids removal.
- The excess sludge from subsequent secondary treatment can also be digested in the anaerobic pond.
- Economical to build and operate.
- Can be managed relatively easily by small and medium-sized communities.

Considerations

- Take time to reach full treatment efficiency.
- Require larger amounts of land compared to conventional activated sludge or other secondary treatment technologies.
- Strategy for sludge removal from the pond should always be part of the design already and not left to the operator.

Technical features and requirements

Anaerobic ponds are normally rectangular basins, ideally with a length to width ratio of about 2 to 1 or larger. The water depth should be at least 3 meters and ideally 5 meters, plus a minimum of 0.5 meters freeboard. Individual ponds should not be larger than 3 hectare. The sides are normally sloped at 1:2-1:3 internally and 1:1.5-1:2 externally, with the inner slope lined with concrete or bricks, particularly at the transition zone from water to air, and at the bottom. Inlet and outlet should be in diagonally opposite corners of the pond. The inlet should be located below water surface and above sludge level, whereas the outlet should be protected with a scum wall that is 30 cm submerged into the water. For plastic covers mostly HDPE 1.5-2.5 mm is used. The cover has to be UV light resistant, and anchored around the pond perimeter. Due attention must be paid to holding the cover down under gas pressure, permitting biogas migration below the cover, consideration of water level fluctuations, and safe drainage of stormwater. Basins must be desludged periodically, and design and management should reflect this. For example, designs should include provision of a ramp, down which a vehicle or animal-drawn cart can be backed once the pond has been emptied of wastewater. Alternatively there are also floating and underwater sludge dredging devices available on the market.