Danish Energy Agency

Ea Energy Analyses

IB Tech

Biogas Tool

calculating costs and benefits of biogas production in Mexico 2018-2019

Danish Climate and Energy Partnership Programme in Mexico 2017-2020

Bioenergy

BIOGAS TOOL

User Guide

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I. Content

Brief description

This document defines the purpose of the Biogas Tool, provides a brief description of the calculation and estimate methods and a general explanation on how to use it

January, 2019

INTRODUCTION

The biogas tool can be used to obtain a preliminary technical and economic evaluation of projects intending to generate and use of biogas in Mexico. Its data and output can be used to decide whether it is worth doing more thorough and detailed technical evaluations and financial analysis as the next step towards realizing the project.

The tool is mainly useful in the Mexican context as it considers Mexican economic conditions such as equipment and construction costs, energy costs, as well as interest and inflation rates. In addition, the tool contains a “feedstock database” with information on the most relevant substrates in Mexico for co-digestion biogas projects.

1. FEATURES OF THE TOOL

The feedstock database contains 20 substrates characterized by the Mexican Biogas Cluster (CEMIE-BIO) of the Ministry of Energy. This information is documented in the separate report “Feedstock database for biogas in Mexico”. The user can include an optional number of the 20 substrates in the project and he/she has the possibility of introducing one additional feedstock. If an additional feedstock is introduced, the user has to enter the necessary data to enable the tool to perform the calculations. To add flexibility to the tool, the user is also allowed to change specific characterization data and physicochemical data for all the included 20 substrates or some of them. If no new data is introduced, the tool will use the default data provided by the biogas experts of CEMIE-BIO. The tool can consider up to 21 feedstocks in co-digestion processes for the estimate of biogas production.

Once the feedstock data has been introduced, the tool calculates the physicochemical data of the resulting mixture (Mass Balance), considering the quantity of each of the substrates. The tool is able to suggest an optimal mixture with a validation of the parameters: biogas production, solids content, biodegradability and grease and oil concentration, which significantly influence the performance of the process. Subsequently, the tool suggests the most appropriate anaerobic digestion technology; however, the user is free to select the recommended option or another alternative. Next, the tool calculates at a conceptual level, the main unit processes related to anaerobic digestion technology. Besides, the appliance displays a simplified process diagram (PD) and, if strictly necessary for the type of substrate, it can be considered to include a pretreatment step for the main treatment to function properly.

After having entered the substrate data and selected the biogas digestion technology, the tool requests the selection of the biogas use: cogeneration of heat and energy, heat production, electricity generation, only biogas burning or sale of biogas. In accordance with the above, the simulator calculates the annual biogas yield, the generation of biomass and the digestate (fertilizer), the possible annual production of electricity and heat (as the case may be), as well as economic benefits related to the use of the biogas. Collateral benefits are also estimated (mitigation of Green House Gas emissions and biofertilizer production).

The simulator has important attributes such as its ease of use since it has buttons that allow quick and simple navigation through the tool, as well as its transparency and flexibility. The user can review the calculation memory for the conceptual design and cost evaluation. It is possible to modify the support formulas and calculation algorithms of the tool. And, it is even possible to add any other calculations that the user might be able to handle.

In addition to the adjustment of the feedstock characterization, it is possible to modify other values, such as energy costs, costs of equipment and supplies, reagents costs, land costs, transportation and disposal of solids costs, or figures for project evaluation time, annual interest rate, minimum payback period and minimum acceptable rate of return (MARR). Likewise, the design parameters can be modified, although it is advisable to have deep knowledge about anaerobic digestion processes and the design and application of existing technologies for biogas production in order to do so.

Because of this flexibility, the use of the tool, including any modification of the default data, formulae or calculation algorithms is the entirely the responsibility of the user.

2. BIOGAS TOOL USER PROFILE

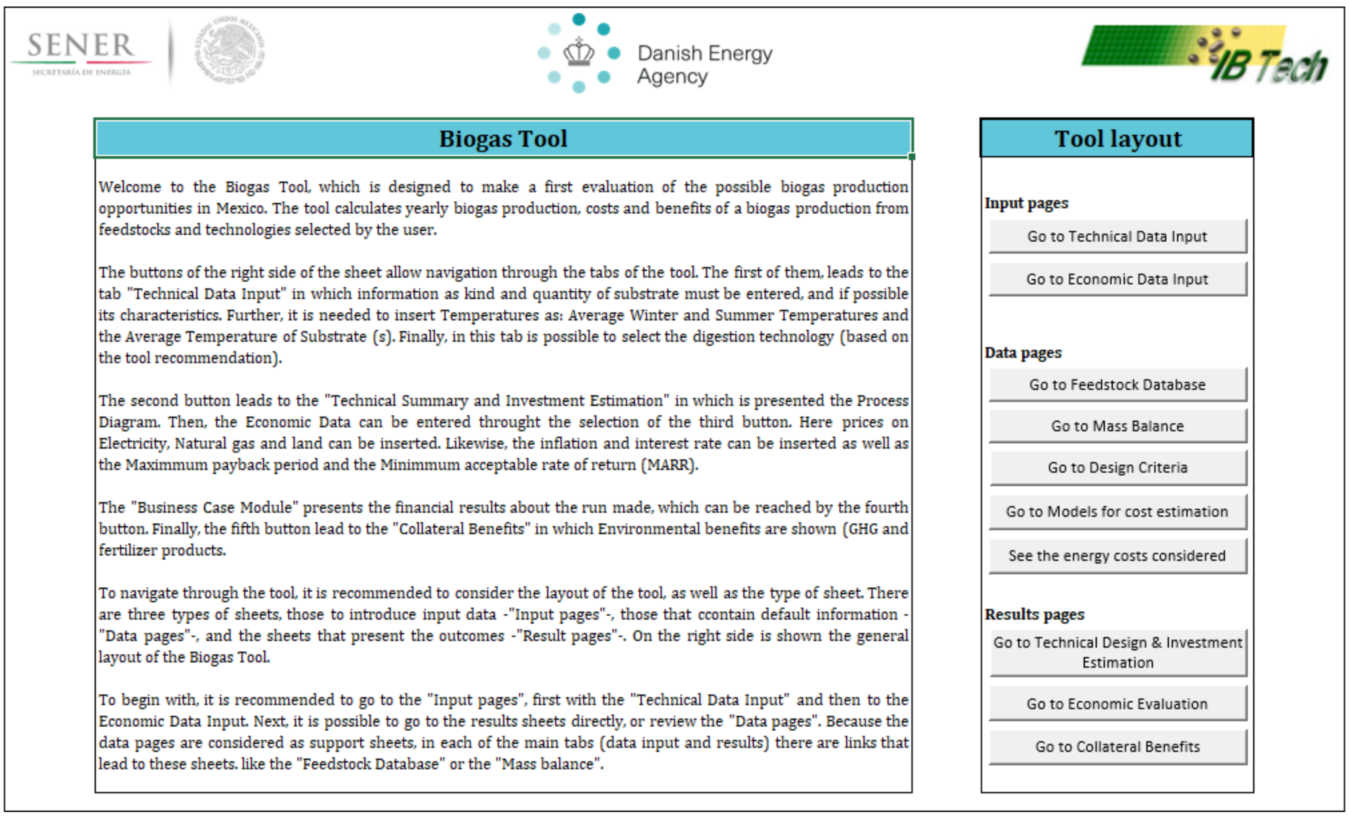
The expected users of the Biogas Tool include:

- Technical/ non-technical users who have to prepare budgetary information for decision-makers in biogas generation projects
- Consultants involved in the development of biogas generation projects
- The decision makers (federal, state, local) themselves
- People who have processes that generate potentially usable waste for the generation of biogas
- Operators of Biogas plants

Or any other person who wants to preliminary evaluate biogas generation projects and, if applicable, continue with pre-feasibility level projects.

3. BIOGAS TOOL STRUCTURE

When opening the biogas tool, the General information sheet (General Tab) is presented, where the objective and operation of the tool is explained in a general way. In this sheet is presented the layout of the tool and a recommendation of the navigation through it. There are three types of sheets: Input pages, Data pages and Result pages. Within each category, the 10 buttons that lead to each of the pages (or sections) are shown. These buttons allow navigating through the elements of the tool.



As mentioned before there are three kinds of sheets (or sections) in the biogas tool, according to their function:

I. **Input pages**. The navigation starts with these sheets to introduce the data needed to simulate the process.
   a. Technical Data Input
   b. Economic Data Input

II. **Data pages**. These sheets are support since they show all the information considered for the simulation.
   a. Feedstock Database
   b. Mass balance

c. Design criteria
d. Models for cost estimation
e. Energy costs considered

III. **Results pages**. They are the main sheets with the outcomes of the simulation.

a. Technical Design and Investment Estimation
b. Economic Evaluation
c. Collateral Benefits

4. OVERALL DESCRIPTION OF THE THREE TECHNOLOGIES FOR THE BIOGAS PRODUCTION

A. ANAEROBIC LAGOON (AL)

An Anaerobic lagoon is an in-ground earthen or lined basin with an impermeable gas-collecting cover. In the lagoon, an anaerobic microbial process degrades and stabilizes organic matter of solid or liquid waste whereby methane is produced. Anaerobic lagoons are not heated, and they are only partially mixed, so they are considered a low rate anaerobic process. The typical depth of the anaerobic lagoons is between 2.4 and 6 meters; however, depths around 5 or 6 meters are recommended. These depths allow a small area and the liquid temperature can be easily maintained. The volume of the pond is enough to permit the sedimentation of settleable solids, an appropriate sludge retention time (always more than 30 days) and almost complete decomposition of the soluble organic fraction of the feedstock.

Anaerobic Lagoon (AL)
Rastro Frigorífico y Servicios Integrales del Bajío, S.A. de C.V. León; in Leon, Guanajuato

Raw liquid waste enters near the bottom of the lagoon and partially mixes with the sludge blanket for example by means of a submerged mixer or by a liquid recirculation current pumped on an intermittent schedule. The effluent discharge is located on the opposite side of the influent. The liquid effluent contains valuable nutrients and is not appropriate to discharge into water bodies (it does not comply with the Mexican permit limits).

The anaerobic lagoon is usually after a bar screen that prevents large/medium size solids to enter the basin. To collect the biogas generated in the process, a flexible cover needs to be installed on top of the lagoon, anchored to the borders.

The design is normally based on organic loading rates and hydraulic retention times derived from pilot plants and mainly from heuristic data obtained from operation experience of existing systems. The values for the main design parameters are shown below:

Organic Loading rate: Typical loading rates are between 0.04 and 0.3 $kg_{DQO}/m^3/d$, varying with feedstock temperature.

Hydraulic detention time: Characteristic retention times vary from 40 to 60 days, also being dependent on substrate temperature.

Lagoon dimensions: Usually, surface areas range from 0.2 to 0.8 hectares. It is advisable to make the lagoon as deep as feasible, since, at a greater depth, heat retention is improved.

In addition to the design parameters mentioned, the operation of a lagoon depends on the temperature and pH conditions. The optimum temperature of the substrate is between 25°C and 35°C, while the recommended pH range is 6.6-7.6. In principle, co-digestion is not recommendable in anaerobic lagoons unless a readily biodegradable substrate is the main feedstock of the mixture.

B. CONTINUOUS STIRRED-TANK REACTOR (CSTR)

Continuous stirred tank reactors are usually a single stage anaerobic reactor system constructed in steel or concrete. This type of reactors is completely mixed, normally on a continuous basis, but it can be done as a batch sequence. Because of the mixing, less than 15% of total solids (TS) is recommended in the feedstocks, thus the process is wet anaerobic digestion. The retention time is about 15-30 days depending on the type of feedstock and its temperature. With substrates that include fats and proteins or other slowly degradable substrates, the retention time can be longer than 30 days. Although it is a technology with long residence times (greater than dry digestion technologies), this technology has the advantage of its operational simplicity. This type of digester is well suited for co-digestion of organic substrates.

CSTR digester
PTAR Sistema Ecológico (CCM-Heineken); in Toluca, Estado de México

The conditioning steps for this type of technology include feedstock grinding and mixing, and sometimes a previous removal of very coarse inert particles. In order to keep the total solids content below 15%, it is necessary to use substrates with low dry matter content, for example, slurry, or to add water, which translates into large volumes of the reactor, increasing investment costs.

The temperature is an important parameter to be considered for the reactor design. Normally CSTR-reactors are described as either mesophilic, with a temperature between 30-45°C, or thermophilic, with a temperature between 50-60°C. The choice of operation temperature can be a function of the available feedstock and its origin, project site logistics, costs for heating and the end use of the digestate. Thermophilic systems can provide additional pathogen kill efficiency compared to mesophilic systems. However, this additional efficiency implies the need to apply more energy to provide the heat to maintain the reactor at 52 - 55°C, the optimal thermophilic temperature.

Heating systems. Digesters need to be kept at a steady, warm temperature for optimum gas yield and stable system operation. The heat requirements can be provided by the Combined Heat & Power Systems (CHP) or by a supplementary gas boiler (especially during start-up) which provide hot water to the digester. The hot water transfers heat to the digester’s liquid content by means of a heat exchanger.

Mixing systems. There are three ways to perform mixing in CSTR systems: by compressed biogas, by mechanical or hydraulic mixing systems.

The design criteria for the completely mixed digester design are the following:

Organic Loading rate: Depends on the feedstock, as well as the temperature and the process. Typically, organic loads range 1 to 5 $kg_{VS}/m^3 \cdot d$.

Hydraulic retention time: As mentioned before, the retention time is usually 15 to 30 days, although depending on the conditions it may be greater than 30 days.

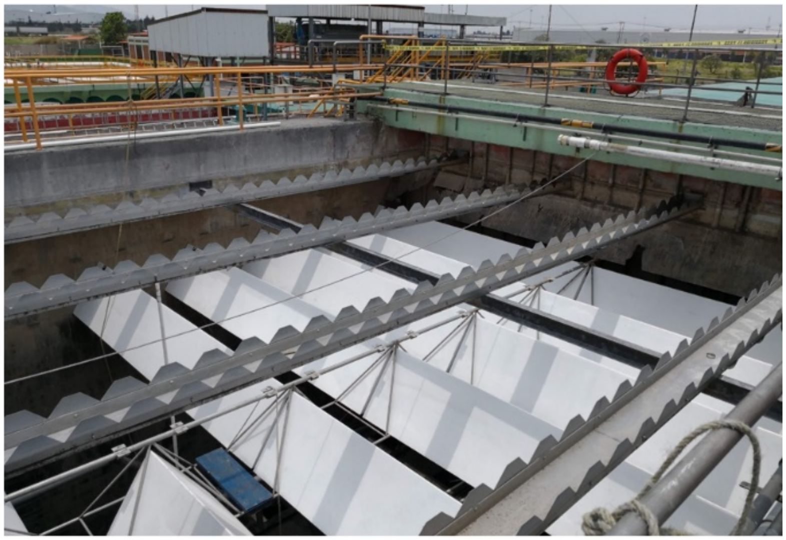
C. UPFLOW ANAEROBIC SLUDGE BLANKET (UASB)

An upflow anaerobic sludge blanket reactor (UASB) is a high-rate single vertical tank that has been used widely for industrial effluents discharged by distilleries, breweries, food processing processes, and highly concentrated wastewaters. The wastewater enters the reactor from the bottom and rises through the reactor while the substrate is treated anaerobically by the granular sludge in suspension. The clarified effluent is extracted from the top of the tank. A UASB reactor comprises of a gas-solids-liquid separator, an influent distribution system, and an effluent extraction system.

The contact between the sludge and the feedstock is guaranteed due to the distribution system of influents, the rising regime and the movement of the biogas bubbles allow an adequate mixture without mechanical assistance. Higher loads can be supported than in flocculating bed reactors. In addition, the baffles (separators) allow the gases to escape, avoiding the washout of the sludge along with the treated effluent. UASB reactors can be built of concrete or another watertight material such as welded stainless-steel sheets or bolted carbon steel with an appropriate proper corrosion resistant coating and can be designed in a circular or rectangular section.

The main influencing parameters involved in a UASB design are pH, temperature, chemical oxygen demand (COD), volumetric COD loads, hydraulic retention times and upflow water velocity. Temperature and pH are both important parameters for an anaerobic digester design either UASB, lagoon or digester completely mixed, as mentioned in the description of the previous processes.

COD loads: Influents should have concentrations of above 600 mg_{COD}/L, as for lower concentrations, anaerobic digestion is not beneficial. Optimum influent concentrations are above 2 000 mg_{COD}/L and an upper limit is not known.


Upflow Anaerobic Sludge Blanket (UASB)

Organic Loading rate: Depends on the feedstock, as well as the temperature and the process. Typically, organic loading rates range from 4 to 12 $kg_{COD}/m^3 \cdot d$.

Hydraulic Retention Time (HRT): Typically, 5 days or less

Upflow velocity: An upflow velocity of 0.7 to 1 m/h must be maintained to keep the sludge blanket in suspension and it is not that high to have a sludge washout (this occurs when the anaerobic sludge is drawn into the outlet due to the high velocity of the water fed).

Primary settling is usually not required before the UASB and co-digestion is recommendable as long as TSS in the effluent are maintained below 2 000 mg/L and the solids are readily biodegradable.

5. PROS AND CONS ABOUT EACH TECHNOLOGY

TECHNOLOGY	ADVANTAGES	DISADVANTAGES
Anaerobic lagoon (AL)	• Low investment costs • Simple operation • Reasonable stabilization of strong organic wastes at a very low operating costs. • Do not require additional energy (they are not heated or mixed). • Less expensive to operate	• Varying and often low-rate biogas production • Requires a relatively large surface. • Environmental conditions directly impact operations (e.g. temperature fluctuations). • Removal of sediments can be difficult
Continuous Stirred-tank reactor (CSTR)	• High efficiency of the anaerobic process, and thus high biogas production • Continuous or batch operation • Good temperature control and control in general. Readily adapted for automatic control. • Nearly perfect mixed. • Extensively modeled (predictable performance). • Suitable for a wide range of feedstocks and co-digestion	• Higher investment and operational costs than AL • High shear stress of impellers if mechanical mixing is used • Lower conversion per unit volume than UASB reactor, and also a less efficient in the COD-methane conversion. By-passing and channeling possible with poor agitation. • Moving internal parts • Requires an expert design, construction, and operation in comparison with AL. • Requires energy for heating and mixing. •
Upflow Anaerobic Sludge Blanket (UASB)	• Very high-efficiency anaerobic process, because it has a high COD-methane conversion. • Continuous operation • Can withstand high organic and hydraulic loading rates. • Low land demand, it can be constructed underground and with locally available material. • No heating of the reactor is necessary. The UASB is already a high rate process that does not require heating or mixing to have high efficiency.	• Treatment may be unstable with variable hydraulic and organic loads. • Long start-up time to work at full capacity. • Not adapted for cold regions. • Requires expert design, construction, and operation in comparison with AL. • Higher investment costs than AL, but lower compared to CSTR digesters. • It is not suitable for high concentrations of suspended solids.

6. THE LOGIC AND DATA INPUT BEHIND THE COSTING

To estimate the costs, three reactor sizes were considered for each of the technologies reviewed in order to perform a scaling estimate method:

- **Anaerobic Lagoons (AL)**: Reactor sizes of 250, 2 000 and 15 000 m^3.
- **Continuous Stirred-Tank Reactor (CSTR)**: Reactor of the following volumes were considered: 200, 1 000 and 5 000 m^3.
- **Upflow Anaerobic Sludge Blanket (UASB)**: 50, 500 and 3 000 m^3 were the volumes contemplated for the estimate.

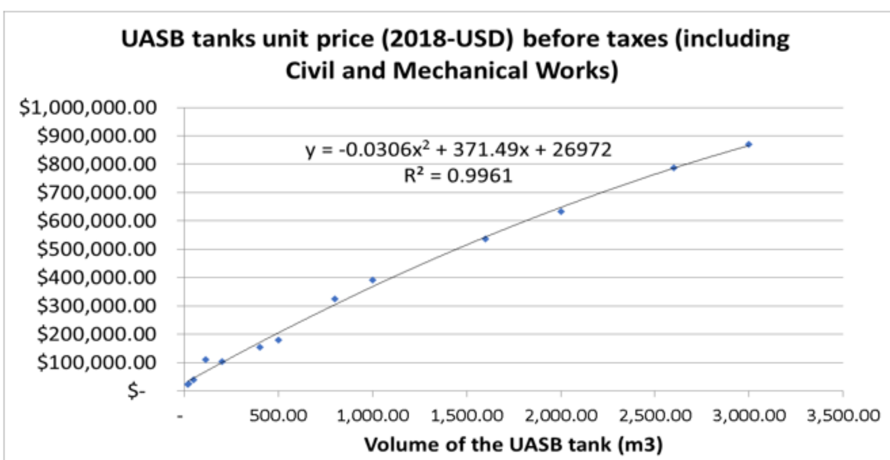
However, since the volume of the digesters and biogas obtained are not necessarily proportional to the mass flow of feedstock (they depend on feedstock organic matter concentrations), quotations of previously executed projects were considered; likewise, quotations were provided for certain very important equipment, such as gasholder, flares, tankage, and CHP. Estimates or quotes correspond to the main equipment or unit processes for each technology.

The civil and mechanical structures costs were estimated with updated prices of materials in Mexico by the end of 2018.

Regarding the pipes and auxiliary equipment, the cost was estimated as a percentage of the cost of main equipment or main systems based on practical experience for each technology.

With the estimates for the predetermined sizes, models were made that allowed to interpolate or extrapolate sizes of processes that had not been quoted.

For some items, more than one model had to be obtained due to the wide range of sizes resulting in different functions that were applied in some cases. In addition, in cases where the cost corresponded to the smallest equipment quoted, in the estimate function the smallest price was marked as a limit.



E.g. of a model for UASB cost estimation

The models correlate the cost with the most important parameter to be considered in sizing each equipment, unit operation or process. That parameter may be the mass or volumetric flow of the substrate, volume or flow of biogas, energy content, among others.

WHAT DOES EACH TECHNOLOGY INCLUDE?

Pretreatment

If according to its physical characteristics the substrate requires it, pretreatment can be conceived, regardless of the main anaerobic technology to be used. So, conditioning and pretreatment operations are presented before the anaerobic digestion technologies.

If the substrate is liquid like any of the following or some of them are in mixture: leachate landfill, coffee pulp, cheese whey, vinasse, red slaughterhouse wastewater or nejayote, the most suitable process will be the UASB reactor or AL due to the UASB reactor is, in general, more efficient and affordable than the CSTS. On the other hand, the lagoon is the most economical technology of all and has no restrictions on solids concentrations. The pretreatment for the aforementioned substrates would include coarse screening, fine screening, pH adjustment, and homogenization. For these cases, in the estimate, it is also included the hoist, the solids containers, the hopper, and the pumps.

On the other hand, if the feedstock is one of the following solid substrates or contains any of them in the mixture: Organic Fraction of Municipal Solid Waste (OFMSW), food waste (from restaurants), market wastes, nopal residues, water hyacinth or green slaughterhouse wastewater, the pretreatment preconceived includes grinding, mixing of feedstocks and pH adjustment previous to a CSTR or AL.

For the case of the Red slaughterhouse wastewater substrate, which is preferably digested in a UASB reactor, as pretreatment, it is required to use a dissolved air flotation unit (DAF) before the UASB reactor. The cost of this unit operation includes the necessary civil and mechanical works, as well as the air compressor and auxiliary equipment.

Biogas management

The only difference between each of the processes is the operation of anaerobic digestion, with some other small differences in some cases. Therefore, the operations related to the treatment and conditioning of biogas are similar for the three main technologies. Biogas handling facilities cost include the gas holder, the biogas flare and the desulfurization system (if needed).

Gas holder: Comprises outlet and inner layers, gas-tight membrane and panel board and connections.

Biogas flare: Includes accessories (pressure and vacuum assembly relief with flame arrester, check valve, drip traps, regulating pressure valves, etc.

Desulfurization: The desulfurization technology is dependent on the mass of sulfur to be removed. The desulfurization system can be micro-aeration in the digester, ferric oxide filter, biological filter, alkaline scrubber + biological reactor. The cost of this stage includes civil and mechanical works and accessory equipment.

Sludge dehydration

If it is not possible to bring the digestate wet to farmland and in this way reuse to nutrients as fertilizer, it can be necessary to separate the digestate in liquids and solids in order to be able to handle these fractions. This can be done by sedimentation ponds or dewatering operations.

A sedimentation pond is considered only for the anaerobic lagoon process, the cost of which includes the excavation works, liner, and geomembrane.

For all technologies, a sludge dewatering operation such as filter press or sludge centrifuge can be required, depending on the amount of sludge to be dehydrated. The estimate also comprises, in addition to the main equipment, the cost of the anaerobic purge pump, the solids container, and the air compressor.

Energy and heat cogeneration system

The process can be carried out by means of an internal combustion system or a microturbine, according to the amount of biogas generated and the methane content. The cost estimate includes mechanical and civil works.

Anaerobic digestion technology

ANAEROBIC LAGOON (AN)

The process that has as main stage the anaerobic lagoon includes the cost of the lagoon itself, likewise, consists of the excavation, liner, geomembrane and the cover for the collection of the biogas. As well as all the civil, mechanical and electrical works required.

CONTINUOUS STIRRED TANK REACTOR (CSTR)

The CSTR process includes the cost of the tank, the mechanical, civil, electrical and instrumentation works, as well as the required equipment. As the main equipment is the mixer and the heat exchanger, in addition, civil and mechanical works are comprised of installation.

UPFLOW ANAEROBIC SLUDGE BLANKET (UASB)

The cost estimate of the UASB reactor includes the reactor itself, the primary distribution box, the recirculation pump, the recirculation pump hoist, the collection gutters, and biogas collection systems. It also includes the mechanical, civil, electrical and instrumentation works.

HOW TO USE THE BIOGAS TOOL?

General considerations

This User Guide will show you all the elements from the Biogas Tool, in order to make the utilization easy.

Please note that the header of all the sheets from the Biogas Tool shows the project general information (Project name, scenario, responsible, date & location).

Project:		**Date:**	
Scenario:		**Location:**	
Responsible:			

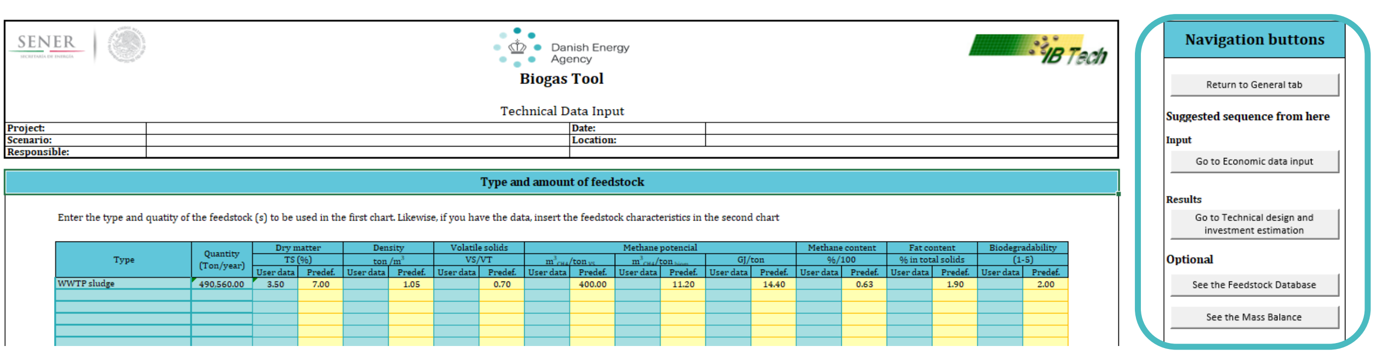
The user has to enter the project information in the blue cells along the Biogas Tool. Yellow cells only show the predefined or calculated data (not able to be modified).

User	Predefined
$60.00	$50.00

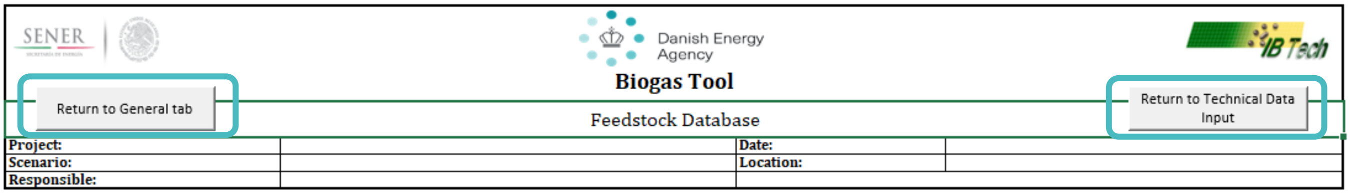
Navigation buttons let the user move forward and backward within the different sheets of the Biogas Tool.

Go to technical design and investment estimation

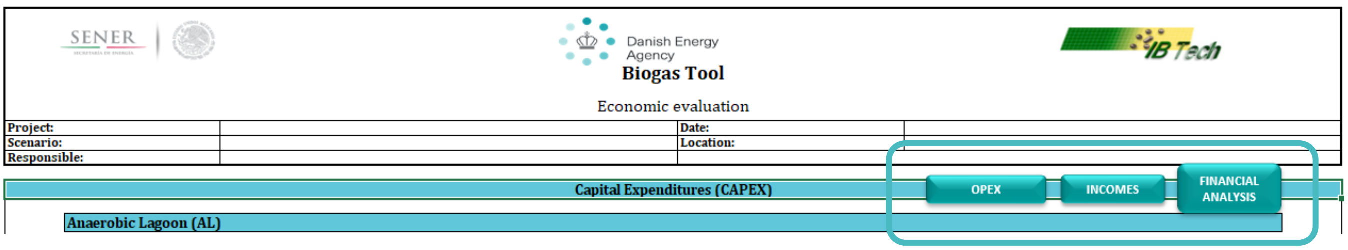
Before going to the instructions, it is important to mention that on each of the main pages, on the right side are the navigations buttons. In addition, the navigation sequence is suggested within the main tabs: Data input and Results. Also support sections are shown: Data pages, which are optional to follow.



In addition, each of the support sections contains buttons to return to the section that was being reviewed or to the General Tab.

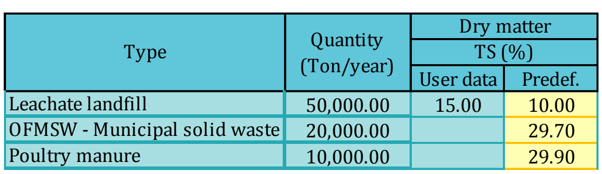


Finally, there are also buttons that allow to go more easily to sections within a page.

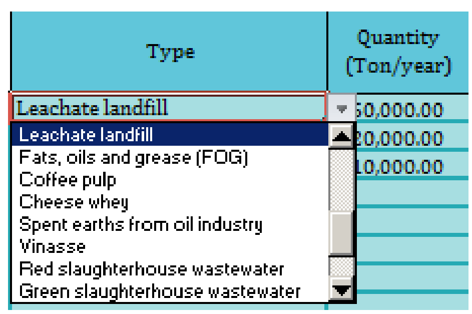


Instructions:

i. Please select the feedstock name from the list. If your feedstock is not in the list, select “Other” and enter the appropriate data, such as dry matter, density, volatile solids, methane potential, methane content, fat content and biodegradability (1 is the less biodegradable and 5 is the most biodegradable).



Type	Quantity (Ton/year)	Dry matter TS (%)	
		User data	Predef.
Leachate landfill	50,000.00	15.00	10.00
OFMSW - Municipal solid waste	20,000.00		29.70
Poultry manure	10,000.00		29.90



ii. If interested in the characteristics of the feedstock, click the button to access the Feedstock Database. It is not necessary to proceed with the simulation.

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Return to General tab

Feedstock Database

Return to Technical Data Input

Project:		**Date:**	
Scenario:		**Location:**	
Responsible:			

Feedstock	Dry matter TS (%)	Volatile solids VS/TS	Biogas potential Nm^3CH_4/ton VS	Biogas potential m^3CH_4/ton biomass	Biogas Potential GJ/ton	Methane content in biogas %/100	Sulphur (H2S) content in biogas %	Biodegradability (1-5)	Fat % in total solids	C/N ratio	Density ton/m^3	TSS/TS ratio	COD/VS ratio	Total N kg_N/ton_{TS}
Poultry manure	29.90	0.65	175.00	35.50	6.30	0.68	0.35	3.00	0.00	9.50	0.35			16.00
Pig manure	32.00	0.64	300.00	31.50	10.80	0.58	0.99	3.00	3.23	10.00	1.13			70.00
Cow manure	55.00	0.64	270.00	20.80	9.70	0.58	1.00	3.00	0.00	10.00	1.13			10.10
Dairy slurry	10.00	0.85	136.00	13.90	4.90	0.55	0.40	2.00	3.23	13.00	0.97			90.00
OFMSW - Municipal solid waste	29.70	0.75	400.00	90.00	14.40	0.65	0.09	5.00	17.50	12.70	1.00			5.40

iii. Read the combined feedstock characteristics in the summary. It is possible to select a button to see the Mass Balance; although it is not basic to continue with the review of the main process.

Characteristics of feedstock to be used

Type	Total Q (Ton/yr)	Dry matter TS (%)	Volatile solids VS/VT	Biogas potencial m^3CH_4/t VS	Biogas potencial m^3CH_4/t biom	Biogas potencial GJ/ton	Fat content % in total solids
WWTP sludge	**490,560.00**	**3.50**	**0.70**	**400.00**	**11.20**	**14.40**	**1.90**

Return to General Tab

Mass balance

Return to Technical Data Input

Feedstock	Quantity (ton/year)	Dry Matter TS (%)	Density (Ton/m^3)	Flow (m^3/year)	Mass flow of solids (ton_{VS}/year)	Volatile solids (VS/VT)	Mass flow of volatile solids (ton_{VS}/year)	Methane potential (m^3_{CH4}/ ton_{VS})	Methane production per year (m^3_{CH4}/year)	Methane potential (m^3_{CH4}/ton $_{biomass}$)	Methane production per year (m^3_{CH4}/year)	Methane potential (GJ/ton_{VS})	Methane content in biogas (%/100)	Sulfur content in biogas (%/100)	Energy generated per year (GJ/year)	Fat content (in % of TS)	Mass flow of fat (ton_{FAT}/ year)	Mass flow of COD (ton_{COD}/ year)	Mass flow of TSS (ton_{TSS}/ year)	N content kg_N/ton_{TS}
WWTP sludge	490,560.000	3.500	1.050	467,200.000	17,169.600	0.700	12,018.720	400.000	4,807,488.000	11.200	5,494,272.000	14.400	0.625	0.500	173,069.568	1.900	326.222			20.000
Co-substrate	490,560.000	3.500	1.050	467,200.000	17,169.600	0.700	12,018.720	400.000	4,807,488.000	11.200	5,494,272.000	14.400	0.625	0.500	173,069.568	1.900	326.222	0.000	0.000	20.000

iv. Take note of the parameter's validation, which is important for the technical feasibility of the project. If some parameter is wrong or out of range, a warning is displayed, and the data can be changed. However, the tool allows continuing with the sizing even if it is shown across. In addition, it is important to mention that the asterisks indicate absence, that is, that there is no feedstock to be recommended to increase biodegradability.

It is not necessary that the validation of the parameters be positive to be able to advance with the review of results. It is only a recommendation to obtain the best results.

Parameter	Validation	Comment
Biogas production	✔	
Solids content	✖	The solids content is not recommended for wet digestion. It is suggested to increase the proportion of wet substrate, otherwise sizing and costing will be out of reality
Biodegradability	✖	The feedstock is slowly biodegradable so it is not recommendable to carry out the digestion or codigestion. It is suggested to improve the feedstock by increasing: *,*,*,*,*,*,*,*,*,*
O & G	✔	

v. Read the recommended technologies for the feedstock (Anaerobic Lagoons are recommended in any case; Upflow Anaerobic Sludge Blanket or Continuous Stirred Tank Reactor are recommended with mutual exclusion). UASB is selected for liquid feedstock (the six mentioned in the section where is explained each technology), CSTR is suggested for the rest of the feedstock, and for co-digestion.

vi. Select the technology to be simulated, based or not in the recommendation. The yellow cell shows the recommended technologies, while in the blue cell, the technology to be evaluated can be selected.

According to the the Data Input, the digestion technology (ies) for biogas production recommended is (are):

Continuous Stirred-Tank Reactor (CSTR) or Anaerobic Lagoon (AL)

Select the technology to be analysed by the tool

Upflow Anaerobic Sludge Blanket (UASB)

vii. In addition to the ability to select anaerobic digestion technology, the user can also select the utilization that will be given to biogas: heat generation, electricity generation, heat and power cogeneration, biogas burnt and sale of biogas.

Select the use of the biogas

Cogeneration of heat and energy

viii. After entering the technical data, click the button “Go to Economic Data Input” to enter the supplies and energy costs if you have them. In this page is possible to introduce other economic parameters as those related to the evaluation of the project. In you do not have the values, the “User” cells are left blank, in this way, the tool selects the predefined values.

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Biogas Tool

Economic Data Input

Project:		**Date:**	
Scenario:		**Location:**	
Responsible:			

Supplies and energy costs

Note: The peso-dollar exchange rate used is November 2018

Cost of the land		
Item	Unit cost (USD/m2)	
	User	Predefined
Land	$60.00	$50.00

Reagent costs

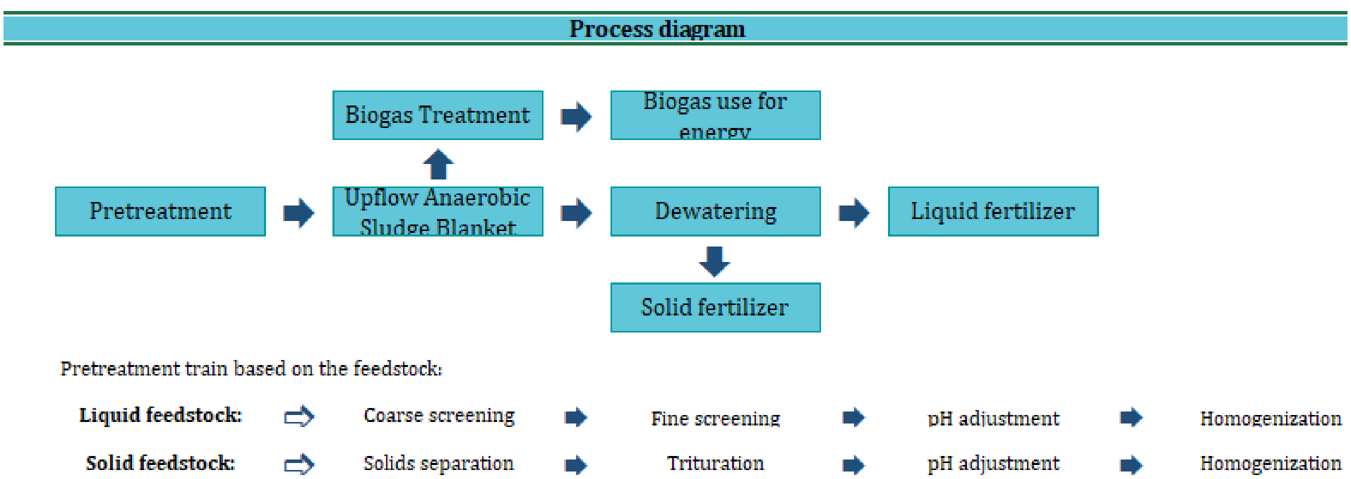
Costs for disposal of solids *** With the anaerobic & biogas project**		
Item	Unit cost (USD)	
	User	Predefined
Transportation (per m^3) (divided by 14 m^3 -truck capa	$1.71	$1.69
Disposal (per ton)	$12.00	$12.11

Costs for disposal of solids *** Without the anaerobic & biogas project**		
Item	Unit cost (USD)	
	User	Predefined
Transportation (per m^3) (divided by 14 m^3 -truck capa	$1.80	$1.69

ix. In Economic Data Input sheet, it is mandatory to select
   a. The type of fuel to be replaced by cogeneration and the Mexican State where the plant may be located.
   b. The Mexican State for the estimate of the electricity cost

x. Cost adjustments may include:
   a. Cost of the land
   b. Cost for solid disposal with the biogas project
   c. Cost for solid disposal without the biogas project
   d. Reagent costs
   e. Cost of the fuel
   f. Fertilizer cost
   g. Interconnection costs and Clean Energy Certificates (CEL) cost
   h. Project evaluation time, inflation, maximum payback period (MPP) and Minimum Acceptable Rate of Return (MARR) for the financial assessment

xi. After entering the economic data, it is suggested to go to the first results tab: Technical Design and Investment Estimation. In this sheet it is possible to see the general Process Diagram, and the pretreatment process suggested.



xii. Also, on the right side of the page, you can select “Go to list of equipment and costs” to see the main equipment and process costed.

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Go to list of equipment & costs

Equipment list and costs

Description			Unit	Capacity	Unit	Capacity	Cost (2018-USD)
Pretreatment (BOTH TECHNOLOGIES)							
Liquid feedstock							
Solid feedstock	Neutralizati	Includes civil and mechanical works.	m3	106.67	m3/h	53.33	$15,264.56
Main process							
Anaerobic Lagoon (AL)		Includes excavation, liner, geomembrane, and cover for biogas collection.	m^3	32,928.00	SRT (d)	25.73	$2,835,053.08
Storage, burner and treatment of biogas							
Anaerobic Lagoon (AL)	Gas holder	Includes outler and inner layers, gas-tight membrane and interface board and connections.	m^3	5,000.00	RT (h)	6.00	$288,617.00
	Biogas burner	Includes accesories (pressure and vaccum assembly relief with flame arrester, check valve, drip traps).	m^3/h	790.27			$342,694.97

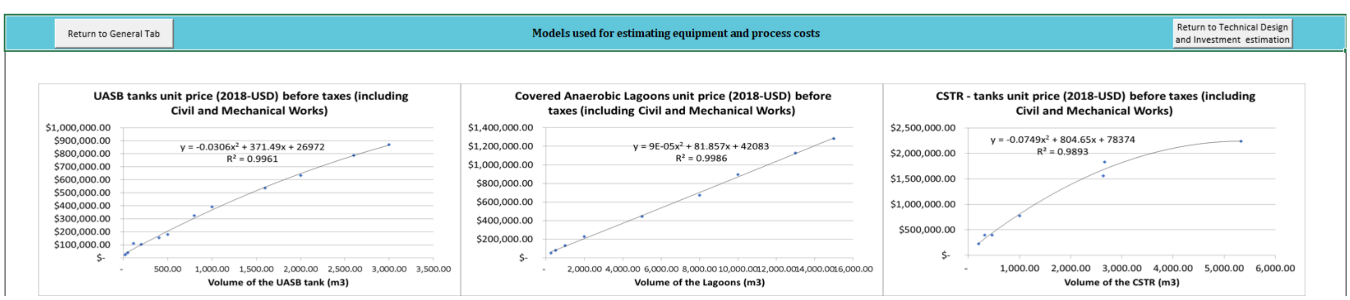
xiii. Optionally, there are the sections: Design criteria for treatment, Design criteria for the main technologies and Models for investment estimation.

Optional

See the design criteria for pretreatment

See the Design Criteria for the main technologies

See the Models for investment estimation



xiv. This sheet (Technical Design and Investment Estimation) includes the memory of calculations of the process, which is shown below the Process Diagram. This table includes:

a. Feedstock properties
b. Biogas properties
c. pH Adjustment
d. Anaerobic digestion with the recommended technologies
e. Sludge generation
f. Biogas production
g. Biogas desulfurization
h. Sludge treatment
i. Cogeneration.
j. Saving calculations from electric power generation
k. Terrain Surface estimate

xv. After reviewing the calculation and costing memory, it is suggested to continue with the second results tab: Economic Evaluation. This sheet presents the CAPEX, the OPEX, as well as the Financial Analysis.

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Biogas Tool

Economic evaluation

Project:		**Date:**	
Scenario:		**Location:**	
Responsible:			

Capital Expenditures (CAPEX) | OPEX | INCOMES | FINANCIAL ANALYSIS

Anaerobic Lagoon (AL)

Investment cost estimate					
Item (includes civil, mechanical and piping works)			**Estimate by the Biogas Tool USD**	**Estimate by the User USD**	**Used estimate USD**
Neutralization	Do you want to include this item?	Yes	$15,264.56		$15,264.56
Anaerobic Lagoon (AL)	Do you want to include this item?	Yes	$2,835,053.08		$2,835,053.08
Gas Holder	Do you want to include this item?	Yes	$288,617.00		$288,617.00
Biogas Burner	Do you want to include this item?	Yes	$342,694.97		$342,694.97
Desulfurization	Do you want to include this item?	Yes	$701,661.66		$701,661.66
Sedimentation lagoon	Do you want to include this item?	Yes	$252,226.74		$252,226.74
Sludge centrifuge	Do you want to include this item?	Yes	$732,830.72		$732,830.72
Internal combustion CHP	Do you want to include this item?	Yes	$4,128,189.97		$4,128,189.97
TOTAL COST OF THE INVESTMENT (ESTIMATE BY THE BIOGAS TOOL)					**$9,296,538.69**
TOTAL COST OF THE INVESTMENT (ESTIMATE BY THE USER)					
TOTAL COST OF THE INVESTMENT TO BE USED IN THE FINANCIAL EVALUATION					**$9,296,538.69**

xvi. The Capital Expenditure (CAPEX) and the Operating Expenses (OPEX) are shown in different sections for both technologies shown (Anaerobic Lagoon [AL] and Upflow Anaerobic Sludge Blanket Reactor [UASB] or Continuous Flow Stirred Tank Reactor [CSTR]).

xvii. Please note that projects above 0.5 MWh/h of installed capacity have to request the permit to the Mexican Energy Regulatory Commission (CRE).

xviii. The user can select the unit operations (items) that will be included in the CAPEX estimate.

xix. It is possible to modify the user's estimated unit price for:

a. Items
b. Total investment
c. Process engineering
d. Start-up
e. Land
f. Taxes and other applicable expenses.

xx. The user may modify monthly costs of the OPEX including:

a. Personnel
b. Administration
c. Maintenance
d. Laboratory
e. Chemical Reagents
f. Biosolids
g. Energy
h. Biogas treatment
i. Other applicable costs

Operating Expenses (OPEX) INCOMES CAPEX

Anaerobic Lagoon (AL)

Item	Monthly cost (USD) by Biogas Tool	Monthly cost (USD) by User	Monthly cost (USD) to use for the financial evaluation
Personnel costs	$2,933.27		$2,933.27

Administration costs			
Item	Monthly cost (USD) by Biogas Tool	Monthly cost (USD) by User	Monthly cost (USD) to use for the financial evaluation
Insurance costs			$0.00
Phone line services	$750.00		$750.00
Cleaning services	$100.00		$100.00
Personnel protection equipment	$75.00		$75.00
SUBTOTAL ADMINISTRATION COSTS			$925.00

Maintenance costs			
Item	Monthly cost (USD) by Biogas Tool	Monthly cost (USD) by User	Monthly cost (USD) to use for the financial evaluation
Vehicles	$200.00		$200.00
Buildings	$395.10		$395.10
Concrete estructures and tankege	$3,160.82		$3,160.82
Steel structures and tankege	$677.87		$677.87
Piping	$116.21		$116.21
Electrical equipment (MCC, panels)	$464.83		$464.83
Mechanical equipment	$8,521.83		$8,521.83
SUBTOTAL MAINTENANCE COSTS			$13,536.66

xxi. The user can see and modify the income, saving parameters for the biogas project, including:

a. Sale of digestate
b. Electricity savings
c. Clean Energy Certificate sale
d. Heat savings
e. Transportation savings
f. Disposal savings

xxii. In the last part of this tab is the Financial Analysis. The user can see the cash flow of the biogas project within the time window established in the Economic Data Input sheet.

xxiii. Final Internal Rate of Return (IRR) payback period and Net Present Value (NPV) are shown to evaluate the business case.

Financial Analysis

Anaerobic Lagoon (AL)

CONCEPT	UNIT	AMOUNT
Investment	USD	$10,970,855.05
Savings	USD/year	$13,558,650.80
Annual running costs	USD/year	$1,450,541.75
Annual rate of increase in the price of electricity	%	5.00%
Annual increase rate of operating costs	%	5.00%
Annual bank interest on net savings	%	0.00%
Annual bank interest on loan	%	5.00%
Number of years in which the debt is paid		8.00
Rescue value		0.00

Savings vs. Interests of the investment in the bank							
Year	Savings	OPEX	Payment of interest to the bank	Net savings	Accumulated net savings with bank interest	CAPEX	Unspent balances
0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$10,970,855.05	$10,970,855.05
1.00	$14,236,583.34	$1,523,068.84	$548,542.75	$12,164,971.75	$12,164,971.75	$0.00	$9,599,498.17
2.00	$14,948,412.51	$1,599,222.28	$479,974.91	$12,869,215.32	$25,034,187.06	$0.00	$8,228,141.29
3.00	$15,695,833.13	$1,679,183.40	$411,407.06	$13,605,242.67	$38,639,429.74	$0.00	$6,856,784.41
4.00	$16,480,624.79	$1,763,142.57	$342,839.22	$14,374,643.00	$53,014,072.74	$0.00	$5,485,427.53
5.00	$17,304,656.03	$1,851,299.69	$274,271.38	$15,179,084.96	$68,193,157.70	$0.00	$4,114,070.64
6.00	$18,169,888.83	$1,943,864.68	$205,703.53	$16,020,320.62	$84,213,478.32	$0.00	$2,742,713.76
7.00	$19,078,383.27	$2,041,057.91	$137,135.69	$16,900,189.67	$101,113,667.99	$0.00	$1,371,356.88
8.00	$20,032,302.43	$2,143,110.81	$68,567.84	$17,820,623.78	$118,934,291.77	$0.00	$0.00
9.00	$21,033,917.56	$2,250,266.35	$0.00	$18,783,651.21	$137,717,942.98	$0.00	$0.00
10.00	$22,085,613.43	$2,362,779.67	$0.00	$19,722,833.77	$157,440,776.74	$0.00	$0.00
11.00	$23,189,894.11	$2,480,918.65	$0.00	$20,708,975.46	$178,149,752.20	$0.00	$0.00
12.00	$24,349,388.81	$2,604,964.58	$0.00	$21,744,424.23	$199,894,176.43	$0.00	$0.00
13.00	$25,566,858.25	$2,735,212.81	$0.00	$22,831,645.44	$222,725,821.87	$0.00	$0.00
14.00	$26,845,201.16	$2,871,973.45	$0.00	$23,973,227.71	$246,699,049.58	$0.00	$0.00
15.00	$28,187,461.22	$3,015,572.12	$0.00	$25,171,889.10	$271,870,938.68	$0.00	$0.00
Time in which the investment is recovered						**ERROR**	**years**
Iteration of the rate i (Change cell M330 -blue- until cell P330 -yellow- (NPV) is zero)					**0.1299**		**$93,487,383.53**
rmin						**-60.00%**	

xxiv. Finally, you can go to the last results tab: Collateral benefits. The environmental benefits of the biogas project are shown for technology the first recommendation being the Anaerobic Lagoon and Upflow Anaerobic Sludge Blanket reactor, and for the second technology recommendation (Anaerobic Lagoon and Continuous Stirred Tank Reactor).

xxv. The collateral benefits include Green House Gases estimates and biofertilizer estimates. The estimate of Green House Gases includes the mitigation due to the avoidance of waste disposal at landfills, to clean energy and to fuel replace. The estimate of biofertilizer includes only the urea equivalence for each biogas project. Both collateral benefits are presented for both technologies a time (Anaerobic Lagoon & UASB/CSTR). UASB or CSTR tags and calculations appear in the same cell, changing according to the project itself. Appropriate references are shown at the end of the sheet.

xxvi. The Green House Gas results show both technologies (Anaerobic Lagoon & UASB/CSTR) in parallel columns. The GHG reduction estimates first present the mitigation (tonCO_2eqq/year) due to the avoidance of waste in sanitary landfills and subsequently the reduction due to clean energy and fuel replace. Finally, it is presented with the sum of all GHG mitigation. As mentioned before, there are 3 scenarios for the destination of biogas, so that, only the reductions for each scenario are shown.

Scenario of the biogas use
Heat production - boiler

Green House Gases

Anaerobic Lagoon			CSTR		
GHG mitigation due to avoidance of waste disposal at landfills	145,378.44	ton CO2 eqq/year	GHG mitigation due to avoidance of waste disposal at landfills	177,684.76	ton CO2 eqq/year
GHG mitigation due to clean energy		No electricity production	GHG mitigation due to clean energy		No electricity production
GHG mitigation due to fuel replace	9,261.38	ton CO2 eqq/year	GHG mitigation due to fuel replace	11,319.47	ton CO2 eqq/year
TOTAL GHG mitigation	**154,639.82**	ton CO2 eqq/year	**TOTAL GHG mitigation**	**189,004.22**	ton CO2 eqq/year

Note: This values are for estimation purposes only. Further considerations have to apply if the green house gas accounting will be utilized for legal compliance, carbon financing or any other applicable use. Fugitive emmisions not included.

The Project Scenario only includes the reduction in carbon emissions by substitution of power from the electric grid.

Biofertilizer

Urea fertilizer equivalent	1,672.36	ton/year

xxvii. The biofertilizer from digestate is calculated with a urea equivalent formula, to obtain the total yearly tonnes of equivalent urea.

Calculations				
Parameter	**Unit**	**Quantity**	**Unit**	**Quantity**
Anaerobic Lagoon				
Baseline Methane Emmissions				
Biogas rate	kg/h	1,002.84	tonne/year	8,784.84
Methane content in the Biogas	%	0.55		
Biogas emission of methane	kg CH_4/h	555.57	tonne CH_4/year	4,866.80
Global Warming Potential of the methane	$kgCO_2eqq/kgCH4$	28.00	$tonneCO_2eqq/tonneCH4$	28.00
Carbon Emissions without biogas flaring	$tCO_2eqq/year$	136,270.51		