Danish Energy Agency

CEDES
Comisión de Ecología y Desarrollo Sustentable del Estado de Sonora

IB Tech

norson

Fypasa

Agua de Hermosillo

Pre-feasibility studies for biogas

in Sonora 2018-2019

Danish Climate and Energy Partnership Programme in Mexico 2017-2020
Bioenergy

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1. INTRODUCTION

1.1. Scope and obj1.1.1.ective of the prefeasibility studies

The Energy Partnership Programme between Mexico and Denmark seeks to provide input for a Mexican biomass roadmap that includes the implementation of an action plan and feasibility studies, as well as the proposal of additional incentives to promote a sustainable use of biomass in the energy mix.

Based on available information the present pre-feasibility study in Sonora was chosen by SENER and Danish Energy Agency as a promising biogas production project in Mexico.

The aim of the "Pre-feasibility studies for biogas in Sonora" is to evaluate if a biogas project at the selected site is feasible, describe the best technical solution and provide the basis for stakeholder decisions on whether to continue the implementation of a new or improved biogas solution. Additionally, the study should address the collateral benefits for the environment and climate change, such as the recycling of nutrients and reduction of greenhouse gas emissions.

The lessons learned in this study, and in similar pre-feasibility studies done in Sonora, can be useful for other potential projects in Mexico. These AD-plants are typically farm-based, lagoon covered biogas plants, varying in size from small household plants of less than 25 m^3 to larger plants with a reactor capacity of more than 1000 m^3. The agricultural plants treat slurry and manure from livestock. Additionally, 9 anaerobic digestion systems treat the sludge at municipal wastewater treatments plants (WWTP) and normally produce electricity for the self-consumption of the plant. Furthermore, there are anaerobic digesters in operation at industries such as breweries, dairy and cheese factories, soft drinks facilities, yeast factories, pulp and paper and paper factories, tequila industry and snacks and candies factories. There are also a few AD reactors in slaughterhouses and meat treatment facilities.

According to recent assessments, AD plants in Mexico are typically not very efficient in terms of energy production, and do not contribute with the SEN (Sistema Eléctrico Nacional). The vast majority of the agricultural plants were established for environmental reasons and many of them just burn the biogas.

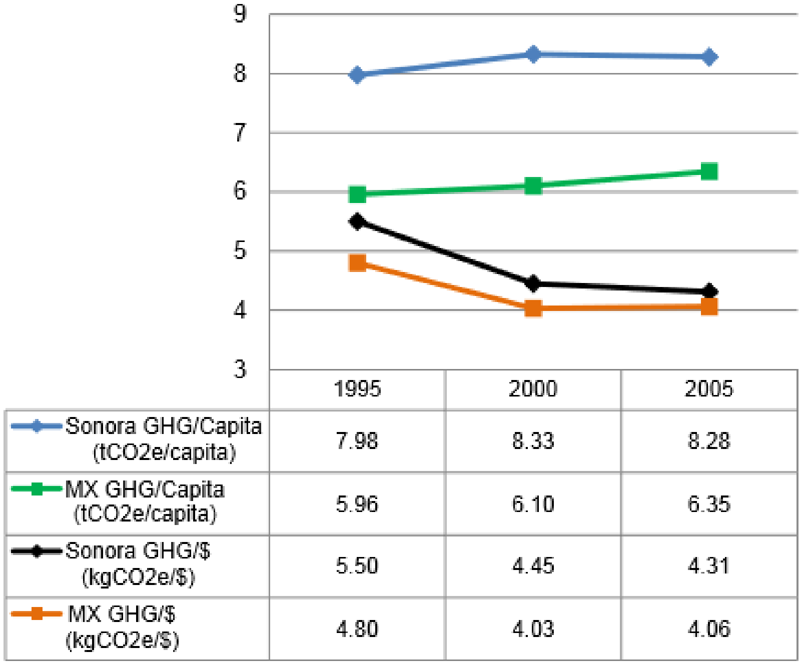
Ultimately, these pre-feasibility studies were intended to identify and analyse technical and regulatory challenges in order to propose specific measures to alleviate the identified problematic barriers. The latter should provide input for future decisions of SENER or at the State level, regarding the role played by biogas in the energy mix in Mexico, which is promising but quite limited in the current situation.

1.1. Sonora framework

The Ecology and Sustainable Development Commission of the State of Sonora (CEDES), that has been involved in the pre-feasibility studies presented in this document, has the mission of establishing public environmental policies aimed at the sustainable development of business activities, the ecological and territorial land use, the promotion of environmental performance and the protection of natural resources.

Sonora is the first state in the country with a green growth strategy, which was developed in conjunction with the Global Green Growth Institute (3GI). This strategy seeks to improve growth, competitiveness and quality of life while optimizing the use of resources and environmental protection.

In the Green Growth Strategy, part of the diagnoses dictate that the intensity of energy in Sonora is higher than the national average (GGGI, 2017). Moreover, although GHG emissions per Gross Domestic Product (GDP) decreased from 2005 to 2015, at the end the GHG emissions *per capita* have increased (as shown in the figure below); this means that GHG emissions in Sonora have increased even faster than the population (BECC-COCEF, 2010).



	1995	2000	2005
◆ Sonora GHG/Capita (tCO2e/capita)	7.98	8.33	8.28
■ MX GHG/Capita (tCO2e/capita)	5.96	6.10	6.35
◆ Sonora GHG/$ (kgCO2e/$)	5.50	4.45	4.31
■ MX GHG/$ (kgCO2e/$)	4.80	4.03	4.06

Figure 0. Historical GHG emissions in Sonora , at national level, per capita and per GDP ($)

Another environmental issue is the handling of solids. According to the diagnosis of the Green Growth Strategy, the proper solid wastes disposal in the state is very low (GGGI, 2017), the vast majority of residues end in one of the 67 open dumps. Under the best scenario, wastes are disposed to a landfill (as it happens in Hermosillo), but the nutrients are not recycled nor is the energy contained in the waste used because there is no collection, burning or use of the generated biogas.

2. SITE VISITS

The consultants visited the following sites in Hermosillo during the field trips that took place on June 14th -15th and August 19th – 20th, both in 2018:

A. Norson pig farms, site 2 (nurseries) and site WTF (Wean-to-Finish)
B. Industrial Park in Hermosillo:
    a. Norson slaughterhouse
    b. Pegson slaughterhouse
    c. Ilis cheese factory
C. Tecmed landfill
D. Hermosillo Wastewater Treatment Plant (WWTP)

Figure 1. shows the main sites for the pre-feasibility study in Sonora.

Figure 1 Main sites for the prefeasibility study in Sonora

The current situation of the visited sites are described below:

2.1. Norson pig farms

Raising pigs in the state of Sonora has been the most productive activity in the northwest region of Mexico; innovation in technology and foreign trade have been two of the main reasons for the growth of pig farms (Bobadilla Soto et al, 2010). In 2017 Sonora produced 206 012 pigs that accounted for 18% of national production that year. Moreover, since 2000 the inventory of living pigs and GHG emissions in Sonora based on pigs has increased 50%, as shown in Figure 2. In 2018 Sonora was recognized for having generated 18 350 tons more than the previous years, in the same period of time (SAGARPA, 2018). There are 83 companies that manage the 349 pig farms in Sonora (SAGARHPA, 2017). Sonora has one of the highest pig-per-farm ratios in the whole country (INEGI,1997).

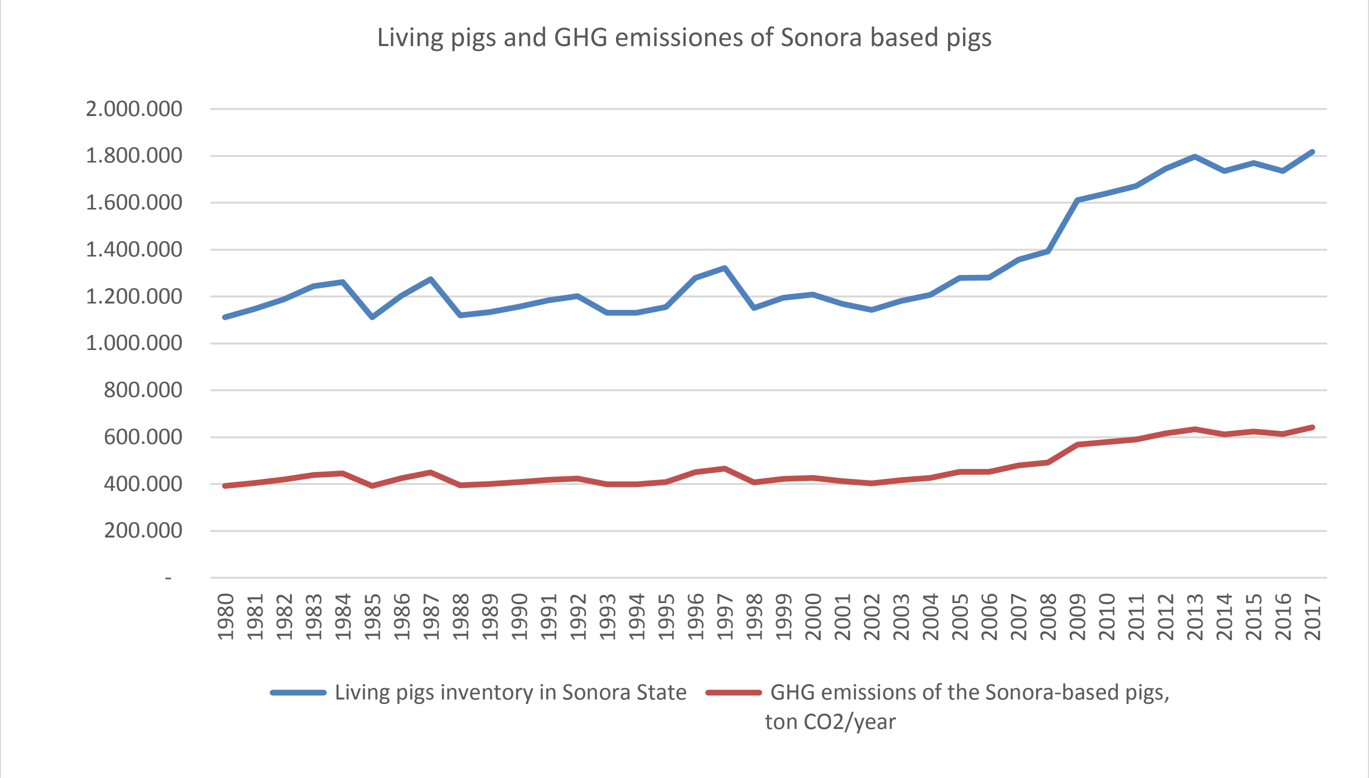


Figure 2. Living pigs and GHG emissions of the Sonora-based pigs

In general, the environmental problems related to pig farms are mainly the following (Pérez,2002):

1. Water pollution due to organic matter, nitrogen and phosphorous
2. Air pollution due to ammonia, sulfurous acid, hydrogen sulfide, methane and carbon dioxide
3. Soil pollution with heavy metals (copper and zinc)
4. Bio risk of diseases for the people in contact with pathogens of the feces
5. Biodiversity reduction

In the specific case of Sonora, it is possible that water pollution and bio risk of diseases are not huge problems due to the desert climate and the fact that, pig farms are far from the urban area.

Norson S. A. de C. V. is a Sonora-based company that produces, processes and sells pig meat; it is located in Hermosillo, the capital of the state of Sonora. It was founded as a joint venture from Grupo ALPRO and Smithfield Foods Inc. in 1999 (Moreno Villegas, 2001). The company has received private and public acknowledgments like the Mexican Exporting Price of 2008, the Corporate Social Responsibility Certificate since 2012 and the National Agri-food Price in 2017. Norson has been the leader of the Sonora-based pork production. In its facilities, Norson includes the raising of pigs, milling of food for pigs, the pig-slaughtering and the pork packaging. During all stages of the value chain and in the entire facilities, Norson ensures the quality of its products. Norson operates management systems for quality, food safety, environmental compliance, occupational health & safety (Norson, 2018).

TYPES OF NORSON FARMS

Norson has 89 pig farms, and like most of the big pig farms companies, these can be of four types:

- ✓ **Type 1**. **Sows and piglets.** The sows are located at this site. Site 1 has more heat requirements due to temperature control. The piglets stay 28 days on this site (21 days minimum).
- ✓ **Type 2. Nurseries**. The piglet remains in this site from weaning (28 days after birth, normally) to 7 weeks. In three sites of this type, 35-50 cm of straw is spread on the floor (in winter the layer is thicker). These sites have 5 buildings, 10 by 150 meters each one and concentrate 50 to 60 percent of weaning capacity.
- ✓ **Type 3. Finishers**. The pigs stay for 18 weeks. These types of farms have the greatest potential to generate energy due to the large number of animals and the production of manure per head. However, these farms have a very low energy demand.
- ✓ **Type 4. Wean to finish**. This is a special site, where the piglets are sent directly from weaning to finishing. The piglets remain in this site for 24 weeks.

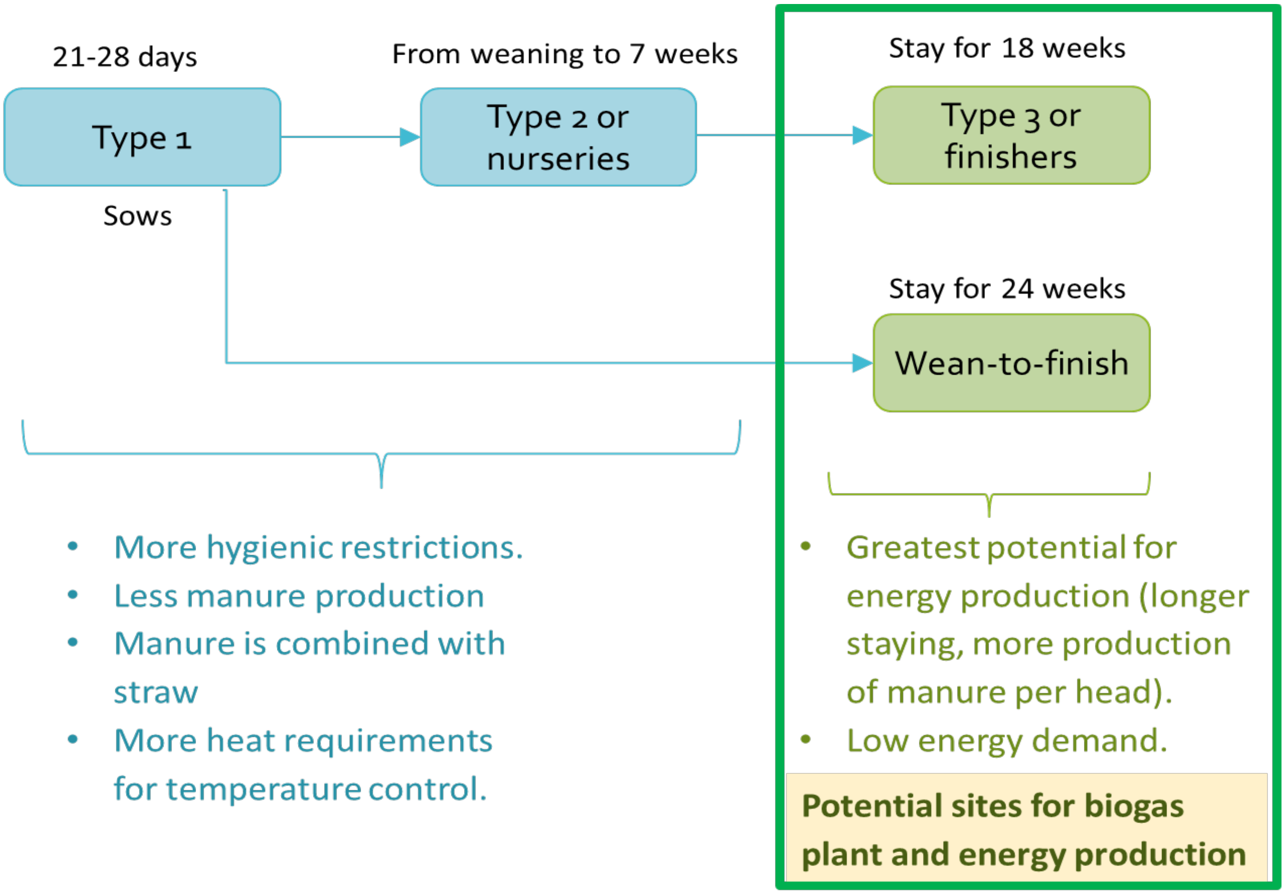


Figure 3. Types of pig farms

Figure 4. "Nurseries"

Figure 5. Wean-to-finish

EXISTING PONDS FOR SLURRY

Farmers use storage ponds for manure collection; in many cases it is just one open pond where the generation of biogas is evident. In a two-pond system, the first one can be covered, and the second one can remain open. Most of the open ponds do not have a subsequent liquid/solids separation so the pond is operated until it is filled with sediments, which would dry after some time. The final dried sediments can be disposed on fields as fertilizer, a practice that does not have full public acceptance. In Norson pig farms, the dried sediments are left in the abandoned pond and a new one is added.

There are 89 farms from Norson nearby (around 60 km radius) producing slurry. Currently, the farms use ponds; however, they were made just to store the slurry. They emit methane that is not captured and some of them are about to be saturated. Only 21 of the ponds are covered and some of them flares the biogas while others are no longer in operation. When the lagoons, covered or not, are filled, the dried manure only remains there, the nutrients are not recirculated, and a new pond is built using new land.

Figure 6. **Location of Norson pig farms in Hermosillo, Sonora.**

Figure 7. Covered anaerobic lagoon not in operation (left) and a not covered lagoon (right); no methane capture and use/burning and no proper treatment and reuse of water and nutrients.

Figure 8. Evaporative ponds; no methane capture and use/burning no proper treatment and reuse of water and nutrients.

VISITED WTF CLUSTER SITE

The consultants of this project visited a cluster of five (5) sites type WTF within a large 5-6 km^2 area, this configuration shows the structure of next generation Norson pig farming. Each farm in the cluster has 8 stables including 1 600 pigs, that equals 12 800 pigs in a farm, and 48 000 pigs in a cluster.

In order to handle the slurry, each farm comprises two big open sedimentation ponds of approximately 22 000 m^3 each, and one smaller evaporation pond. Slurry is led by gravity from 4 stables to the sedimentation pond which has theoretically 1.6 years of hydraulic retention time (HRT). The clarified fraction enters an evaporation pond.

The real HRT is unknown and difficult to calculate due to evaporation (this would increase retention time) and the gradual settling of solids (this would decrease retention time when useful volume decreases as well). The sedimentation lagoons are expected to be abandoned after 15-20 years due to sedimentation.

Currently, the effluent is not used for irrigation (it is just evaporated), and the solids are not used as fertilizer.

Figure 9. Sedimentation pond for four (4) stables of pig farms in WTF.

PROBLEM STATEMENT IN PIG FARMS:

The sedimentation and evaporation ponds have several problems such as 1) methane emissions, 2) there is no clean energy production, 3) water is not reused and 4) there is no recycling of nutrients.

Due to sanitary restrictions, a proper anaerobic treatment of the slurry *in situ* is necessary, in a decentralized way. Any kind of transportation of slurry from one pig farm to another should be avoided, as well as any kind of biogas use that requires contact or movement of vehicles between the pig farms. A pipeline to a gas station outside the farms could be considered, but this installation may increase investment cost. As a result, the option of biogas as fuel for the trucks was discarded at the moment.

PROPOSAL FOR PREFEASIBILITY STUDY 1:

Anaerobic lagoon at WTF pig farm

It was considered that the most appropriate use biogas in this case is the electricity. Norson actually use a diesel generator to produce electricity because the electricity supply is unstable. Electricity network in the WTF farms can be evaluated to maximize the benefits from this.

2.2. Industrial Park

Hermosillo is a city located in the northwestern Mexican state of Sonora. It is the capital and its largest city, as well as the main economic center of the state. As of 2016, the city had a population of 884 273 inhabitants, making it the 15th largest city in Mexico (INEGI, 2017). The recent stimulus in the growth of the population is due to the increase of industrialization. The main economic activities are industry, agriculture, livestock, fisheries and commerce (ProMéxico, 2017). The city was ranked as the seventh most competitive city in the country according to the Mexican Institute for Competitiveness (IMCO).

Nevertheless, Hermosillo is facing several environmental challenges. Some areas in Hermosillo do not have good air quality due mainly to the asphalt factories (Uniradio Noticias, 2018). Sonora river is still contaminated due to toxic leaks from a copper mine since 2014. Further, there is no garbage separation in the city.

Hermosillo has 15 Industrial Parks (H Ayuntamiento de Hermosillo, 2015). One of them located in the southeast of the city, has several food and beverage industries, such as:

- Norson slaughterhouse (pigs)
- Pegson slaughterhouse (cattle and pigs)
- ILIS (milk).

The Hermosillo Industrial Park mentioned before is shown in the following polygon:

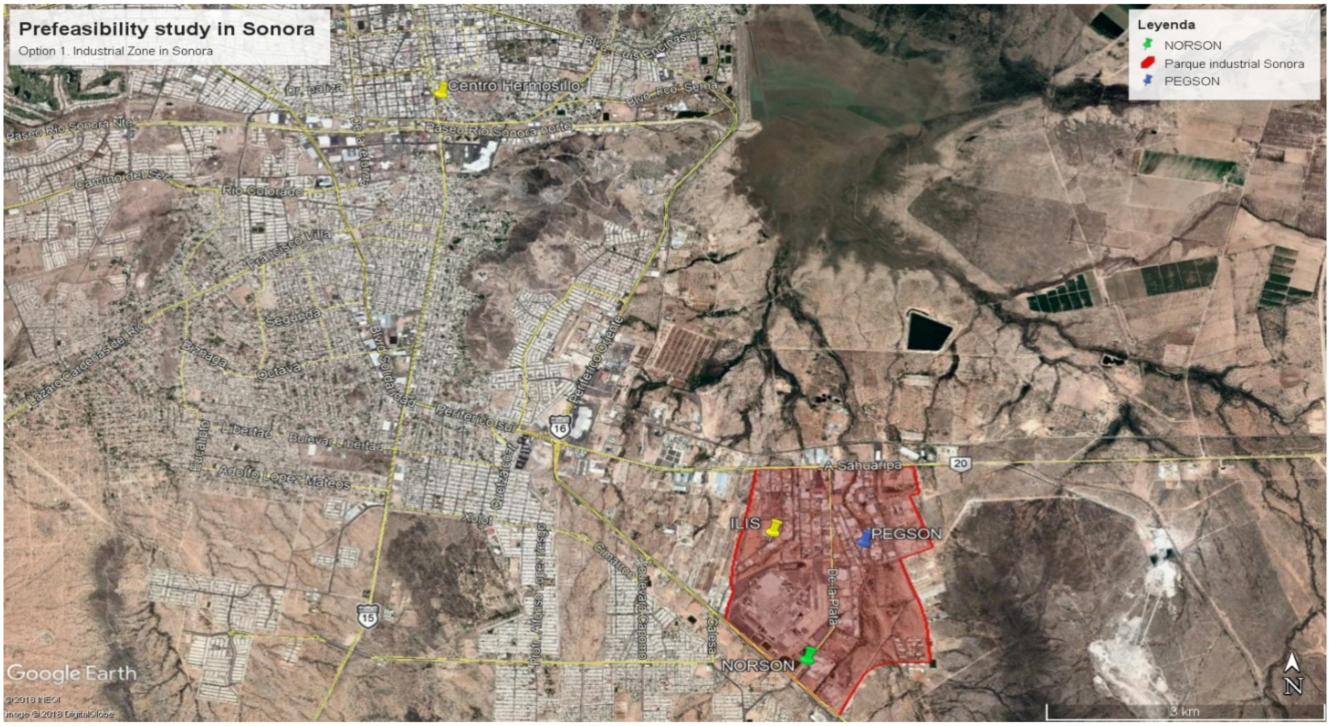


Figure 10. Location of the Hermosillo Industrial Park (F&B)

Figure 11. Location of Norson, Pegson and Ilis at the Hermosillo Industrial Park (F&B)

Hermosillo is one out of five cities in Mexico that treats 100% wastewater discharged at the wastewater treatment plant (WWTP) of Hermosillo, there is also, a landfill operated by the private company TECMED.

2.2.1. Norson slaughterhouse

There are 22 slaughterhouses in the state of Sonora (SENASICA, 2018) from which 9 are trail-federal-inspection (TIFF) slaughterhouses (SAGARHPA, 2017). Sonora has been shown at the lower tier of the slaughterhouse-related bio risk (Signorini, 2008). The slaughterhouses produce environmental impacts due to water consumption, waste generation, soil pollution, wastewater discharges and unpleasant odors (Cadena Velasco, 2009).

Norson is currently upgrading its capacity by installing new production lines. In 2018, there was a slaughter rate of 300 pigs per hour; in 2019 this would increase up to 400-450 pigs per hour. The new lines will reduce water consumption; however, there will be an increase of net wastewater discharge due to the increase of slaughtered animals. Norson working schedule has two shifts, 14 hours per day, 5.6 days per week.

Most of the blood generated is separated (for the purpose of reusing it), and a small percentage is discharged into the drainage. The volume of water consumed and discharged is between 800 and 1 100 m^3 per day. Visceral waste is reused for rendering (animal feed).

Figure 12. **Satellite view of the slaughterhouse and meat processor "Norson"**

Beside the slaughterhouse, Norson has a wastewater treatment plant (WWTP) with the following process:

- ✓ Pumping station
- ✓ Separation of solids (screening)
- ✓ Homogenization tank (1 500 m^3)

- ✓ Chemical dosing for coagulation and flocculation.
- ✓ Air diffusion flotation system (DAF)
- ✓ Storage of fats
- ✓ Discharge of the effluent in the municipal sewers.

42.5 tons of fats (from WWTP screens and others upstream) are generated per month. These are disposed to TECMED landfill.

In the WWTP, the sludge from DAF goes to “drying boxes” before being deposited in TECMED landfill. Approximately, 14 tons of dry-sludge from DAF is produced per month. Due to the high content of fats and moisture in this sludge, it is difficult to transport it in the trucks boxes. Because of this, trucks are filled to 50% capacity.

In the WWTP there is no further removal of contaminants in a biological process. There is no real interest on treating wastewater, only 20 percent of what is paid to discharge corresponds to the excess of pollutants. It is paid 22.9 pesos/m^3 per discharge, while 1.72 pesos/m^3 corresponds to the excess of contaminants. Besides, Norson cannot use the treated wastewater in its production process. Additionally, 360 000 pesos per month are spent for drinking water consumption.

Regarding the energy, Norson consumes 1 565 MWh/month with an average cost of MX$2.3/kWh, this averages an expenditure of 3 600 000 pesos per month and 43 194 000 pesos per year. Additionally, it consumes 382 000 m^3 of natural gas per year, at a cost of 5-8 pesos per cubic meter, giving an annual expense of around 3 million pesos.

Regarding the transport of meat and animals, there are 34 trucks. Half of them travel 480 km, which corresponds to 150 000 km per year; while the remaining 17 trucks travel 320 km daily (100 000 km per year).

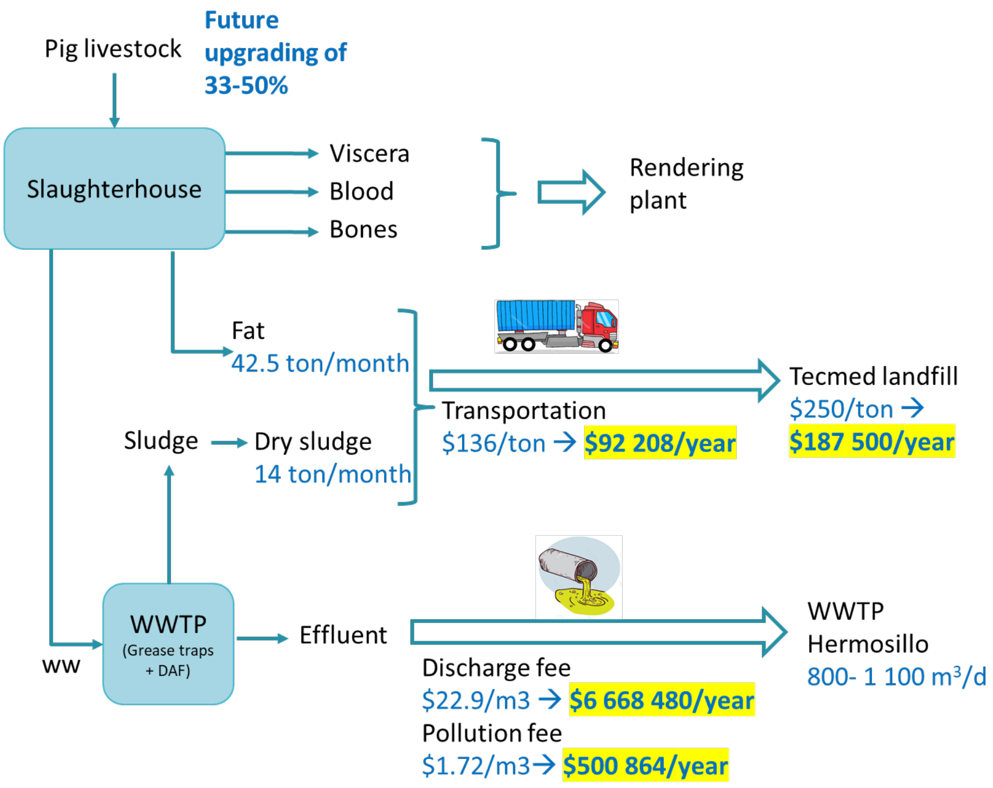


Figure 13. Current mass flow and pollution costs at NORSON slaughterhouse

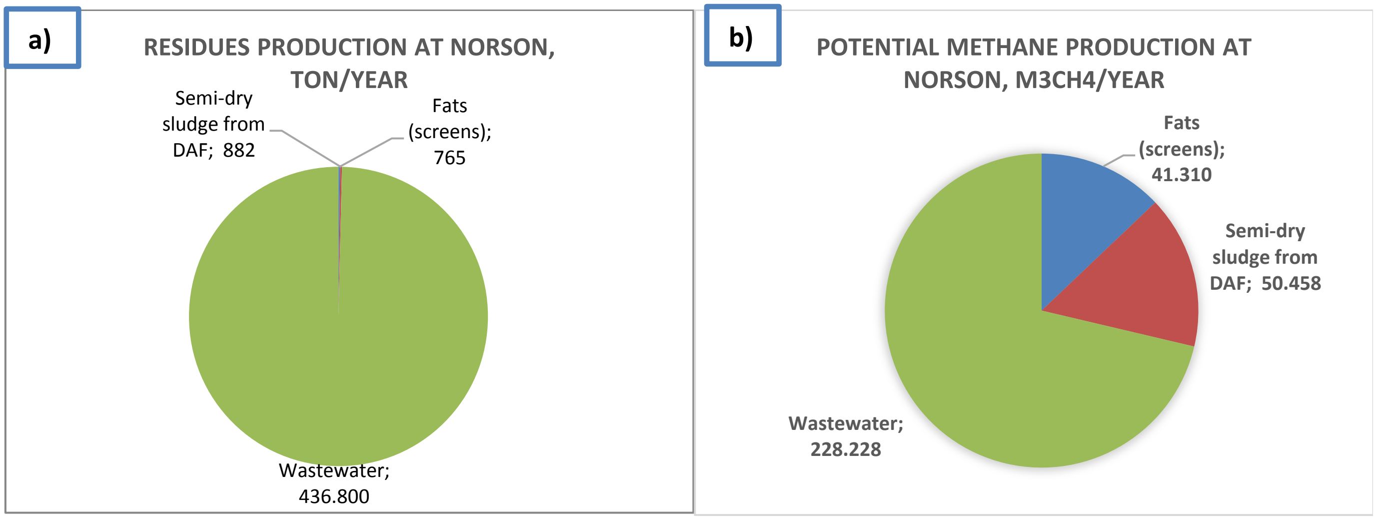


Figure 14. a) Residues production and b) potential methane production at NORSON slaughterhouse

PROBLEM STATEMENT IN NORSON

At Norson, most of the solid waste is used and the cost of disposing it is relatively low (due to the drying solids step). Wastewater discharge represents the greatest economic impact and the greatest potential for methane production. Norson could have area available for a WWTP, but the discharge into the sewers may continue because there are no agricultural areas nearby and treatment for reuse can be very expensive and restricted due to Norson´s sanitary regulations.

Due to the large energy requirements in all areas of its plant (electricity, natural gas, vehicle fuels), Norson could explore the production of biogas and energy by installing an anaerobic wastewater treatment *in situ*. The recommended technology is an Upflow Anaerobic Sludge Blanket (UASB), which will be explained in detail in chapter 3.2. The analysis should be done for a future upgrading scenario of Norson's plant.

PROPOSAL FOR PREFEASIBILITY STUDY 2:

UASB at Norson slaughterhouse

2.2.2. Pegson Slaughterhouse

Pegson is a company that offers slaughter services, by-product management such as viscera and bones and refrigeration of meat products. Additionally, it offers cuts of beef and pork.

This slaughterhouse sacrifices 280 heads per day, mainly cattle. Waste generated in the slaughterhouse are: manure (from barnyard), grease, stomach content (green stream) and wastewater with traces of blood. Blood and viscera are by-products that already have a current use in rendering facilities for pet food production. Figure 15 shows the conveyor screw that carries the ruminal content into the truck for later disposal. Likewise, the Figure 16 shows the fat trap.

Figure 15. Conveyor screw for ruminal content

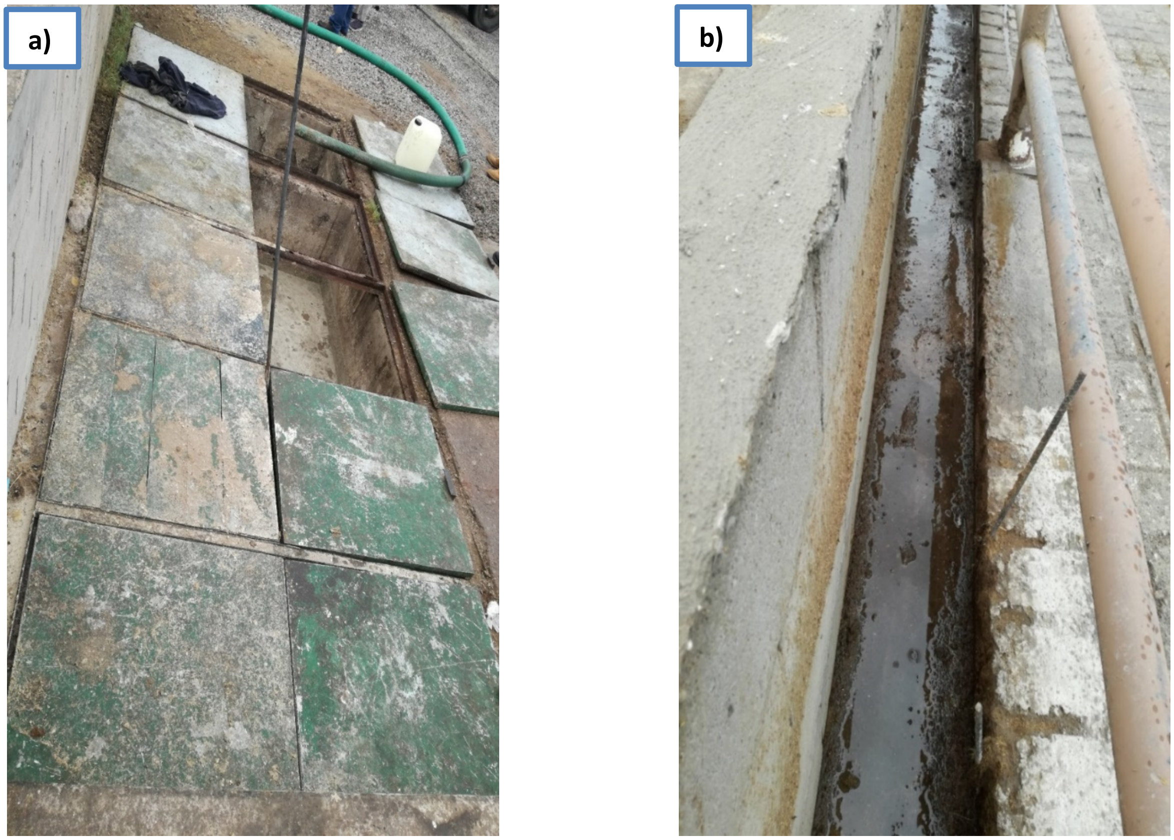


Figure 16. a) Fat trap and b) Manure waste channels at Pegson slaughterhouse.

120 m^3 of waste are generated and disposed in the TECMED sanitary landfill per month, 40 m^3 of this waste correspond to stomach content, 20 m^3 are fats, 40 m^3 are manure (Figure 16 b), manure waste channels) and finally, 20 m^3 is blood -although, nowadays most of the blood already has a use, this 20m^3 is the remaining part that cannot be reused-.

The wastewater generated is sent to the Hermosillo WWTP. The process generates 180 m^3 of wastewater per day, the slaughterhouse works 4 days a week. The fee for the WW disposal is 50 000 pesos/month and includes the fee for exceeding the BOD limits. The pollution fee is low because there are not Municipal Slaughterhouses, so there is an agreement to provide the sacrifice services to the municipality.

2.2.3. ILIS

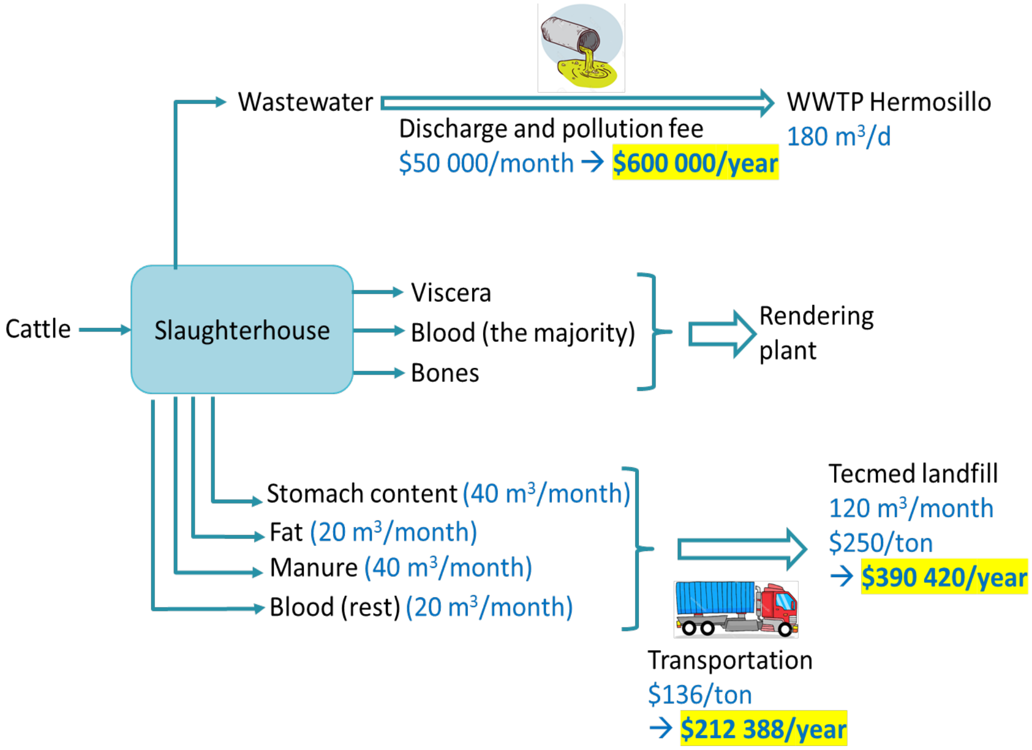


Figure 17. Mass flow and pollution costs at Pegson slaughterhouse

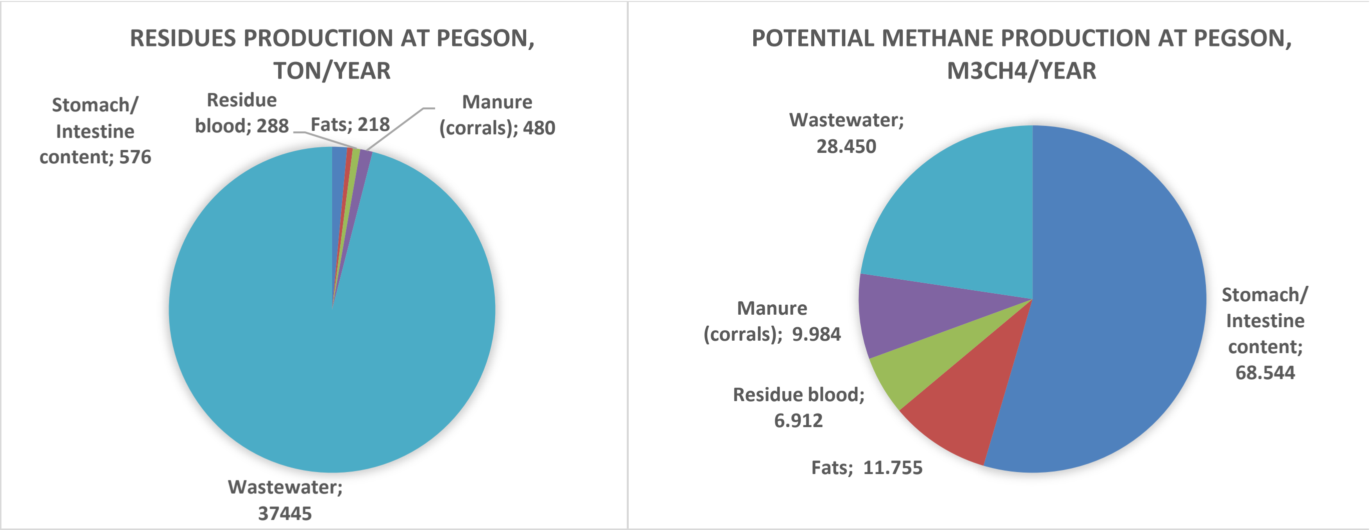


Figure 18. a) Residues production and b) potential methane production at Pegson slaughterhouse

PROBLEM STATEMENT IN PEGSON

At Pegson, the cost of transporting and disposing of solid residues is half the cost of pollution, but these same residues have the greatest potential to produce methane. This waste will have priority for its treatment and reuse.

2.2.3. ILIS

ILIS is a company dedicated to the production of milk and its derivatives, such as: milk formulas, cheese, and ultra-pasteurized milk. The production plant operates 6 days per week. There is a fresh water consumption of 220 m^3 per day; however, there is no flow meter, so it is complicated to determine the wastewater flow discharged (130 m^3/d approximately).

The waste generated by this company comes from the silos and the cleaning of the tanks. Only part of the whey is residue (salty whey); sweet whey is used for milk formulas.

For waste treatment, ILIS has a wastewater treatment plant, which has the following processes:

- Homogenization tank with mixing and aeration (Figure 19 a)
- Pumping
- Flocculator tube (with aluminum sulfate as a coagulant)
- DAF (polymer -super floc A-) (Figure 19 b)
- Sludge container (Figure 19 c)
- Filter press (not used)

Figure 19. **ILIS WWTP: a) Homogenization tank, b) DAF and flocculator, c) Sludge container**

Like Norson plant, ILIS does not have a biological process that guarantees compliance with the regulations. The fee for the use of the sewage is $70 000 per month and for BOD and FOG excess $20 000 per month. The filter press does not work, so the liquid sludge is transported four times a month to a WWTP by a vactor truck owned by PROVISA company. Each month 40 m^3 of sludge is transported so 10 000 pesos are paid per month.

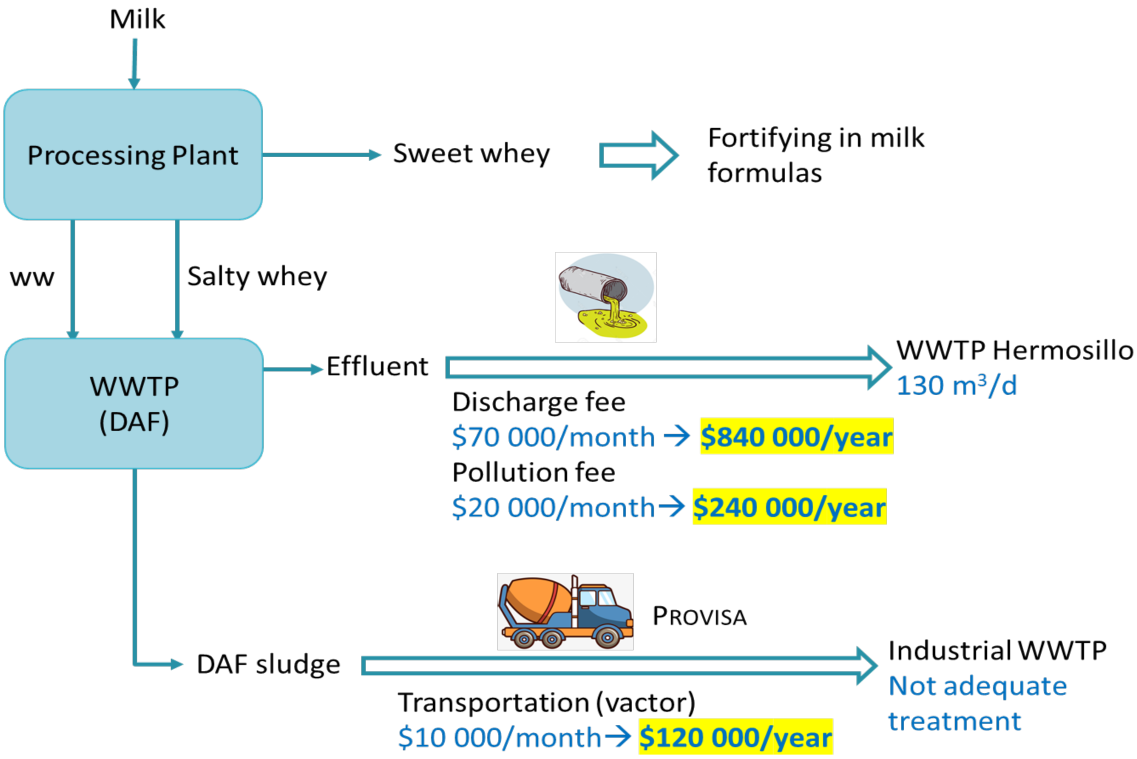


Figure 20. Mass flow and pollution costs at Ilis

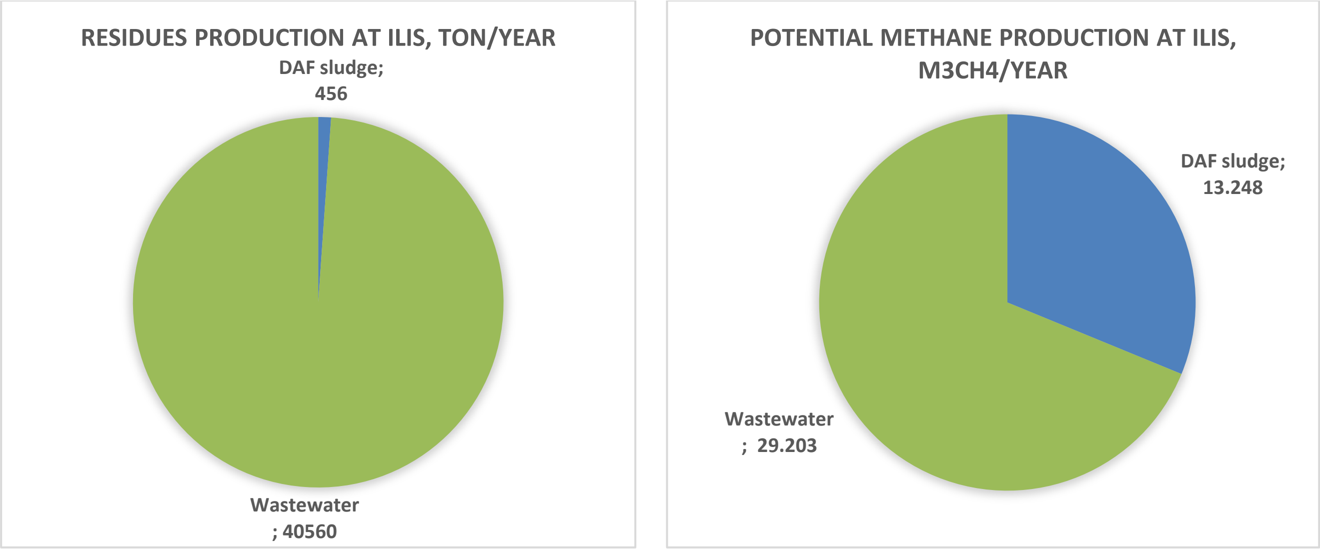


Figure 21. a) Residue production and b) potential methane production at ILLIS

PROBLEM STATEMENT AT ILIS:

At ILIS, all residues are liquid. Both wastewater and DAF sludge have interesting methane potential. Unfortunately, the option of having their own WWTP in site is not economically attractive because there is not much land available in the area, the pollution fees are very low, and the total methane generation is potentially low compared to the expected payback of this kind of companies.

Despite ILIS pays for transport and disposal of DAF sludge, it is not being treated and reused properly at the industrial WWTP.

2.2.4. Problem statement at Industrial Park

- Industries have no real incentives to treat their own wastewater, pollution fees are very low compared to discharge fees.
- Industries at the Industrial Park discharge their wastewater into the sewer system because there are no agricultural areas nearby nor can they be reused in their own food industry plant for sanitary reasons. The municipality could use treated wastewater for irrigation, but this requires high-level treatment that offers no return benefits with the existing fees.
- Industries pays for transport and disposal of solid organic residues, with high biogas generation potential, to a landfill where residues will only be stored and covered. All the nutrients and energy contained in the residues are not used; on the contrary, they represent a source of GHG emissions.
- Industrial wastewater is sent to Hermosillo WWTP, but the WWTP is only planned to treat municipal ww not industrial, where it is treated properly and there are anaerobic digesters.

2.3. TECMED

TECMED is located northeast of the municipality of Hermosillo, 45kms far from the Industrial Park. Figure 22 shows the location of the landfill, likewise, Figure 23 displays the satellite view of TECMED.

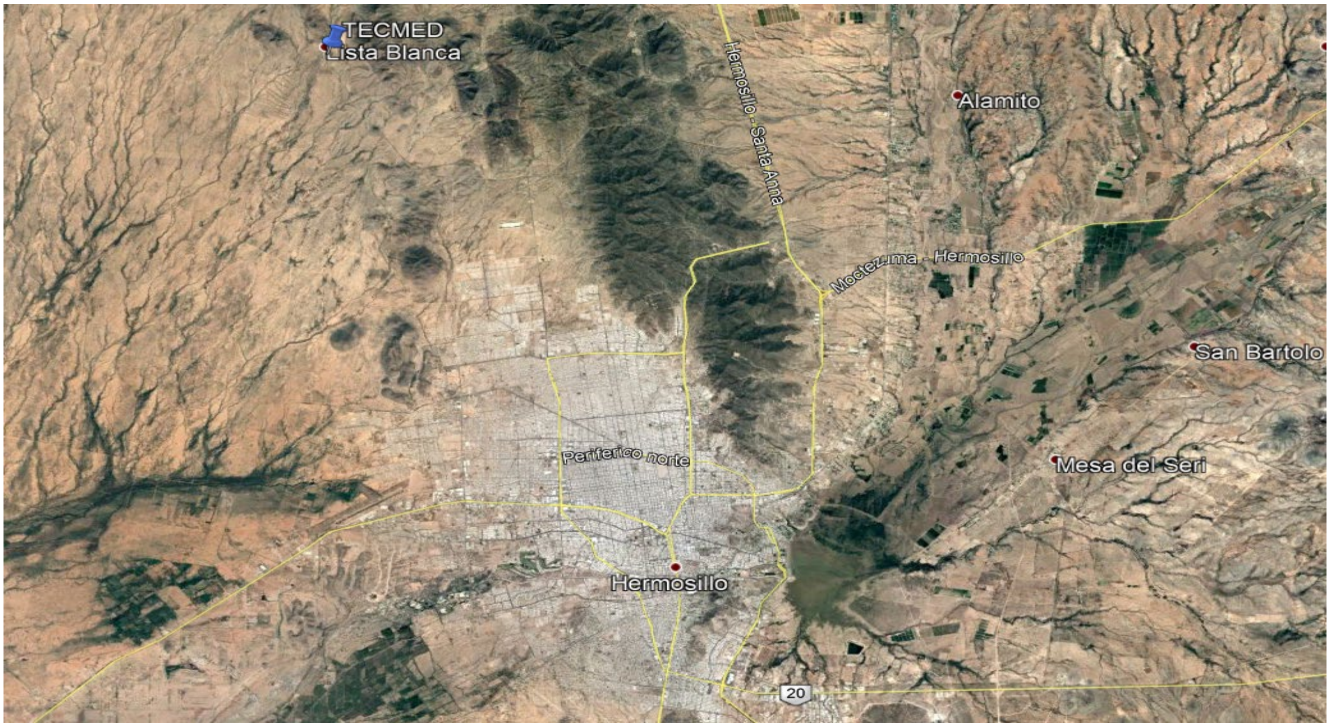


Figure 22. **Location of the landfill TECMED**

Figure 23. **Satellite view of the landfill TECMED**

The municipal government of Hermosillo owns the land of the sanitary landfill; however, TECMED (private company) operates and manages the landfill. In addition to this TECMED operates seven (7) additional landfills, transfers and collects waste throughout the country with greater presence in the state of Sonora. It is important to mention that none of the landfills has biogas collection systems. There is a pipeline project for biogas collection since 2009, but it is currently suspended.

There are 4 cells of 14-16 meters high. They have a first layer of geotextile and geomembrane, and then another layer of 40-60 cm of soil. Three cells are already closed. Cell 1 was closed in 2005, cell 2 in 2009, cell 3 was closed in 2013, cell 4 is still in operation, and there is a plan for a future cell 5. Each cell has a capacity of 12 to 15 million tons of waste.

Although cell number 1 was in operation 13 years ago (from 2001 to 2005), it still emits methane through the venting pipes. Figure 24 shows cell 1, already covered with soil. Every day, 800 tons of garbage is received in TECMED landfill, except on Sundays, when a smaller amount of garbage is collected.

A small quantity of leachate (almost all moisture evaporates) is collected into a sump and then pumped into a dry lagoon. Part of the leachate could seep into groundwater, which is few meters deep (below surface)

All residues are sent to the same place, except for WWTP Hermosillo sludge and slaughterhouses residues. Slaughterhouse residues are received during the night. Additionally, a small amount of construction and demolition waste is received. In the following pictures the heaps of industrial residues can be distinguished.

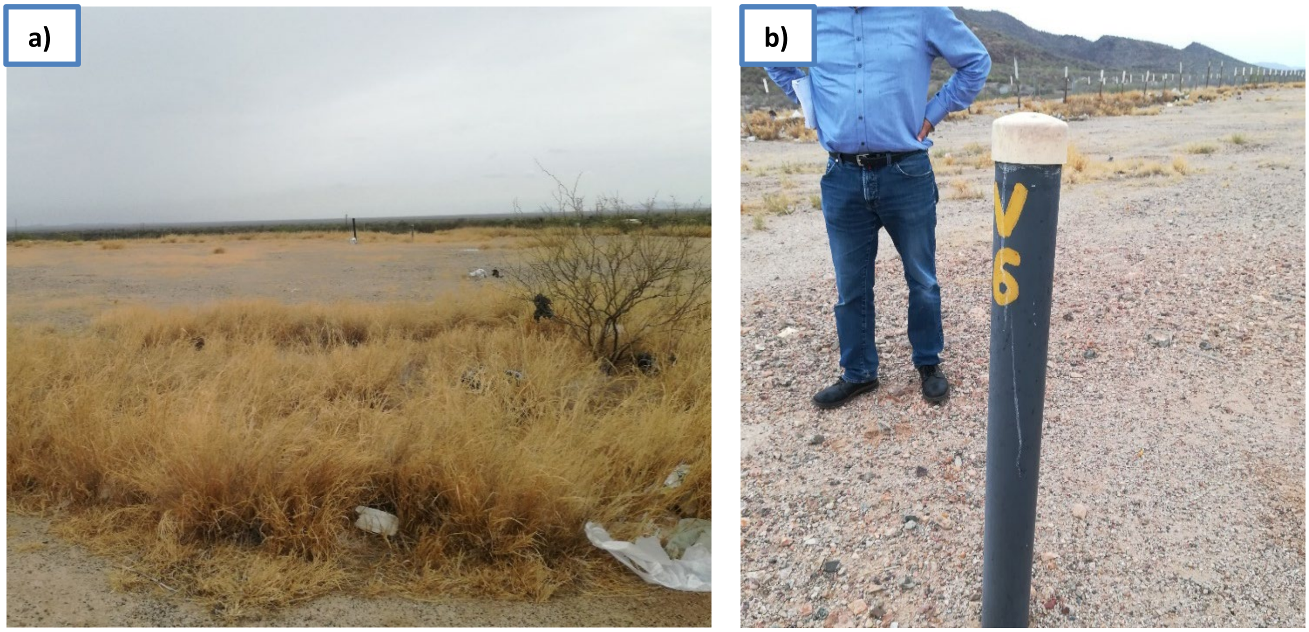


Figure 24. a) Cell 1 sealed with soil and b) venting pipes with methane emissions.

Figure 25. Cells in use

Figure 26. **Heaps of non-municipal residues**

The cost of transporting waste from the Industrial Park (F&B) to the landfill (45 km far) is 136 pesos per ton, while the cost per disposal in TECMED is 250 pesos/ton.

PROBLEM STATEMENT AT TECMED:

Landfill is a technology avoided in Europe, specifically in Denmark, landfilling was taxed in 1987 and banned for all waste which is suitable for recycling or incineration in 1997. Landfills are not a long-term sustainable solution, they represent a garbage storage system that does not allow to use the nutrients contained in residues.

Moreover, in this large specific site (TECMED landfill), the naturally produced biogas is not captured, neither used, so it is a source of GHG emissions instead of producing clean energy.

Of course, installation of landfills is a better option than an un-controlled dump site. But, if a new investment were made that would be for the better and environmentally friendly, even more efficient technologies can be applied in order to treat residues but also to recycle the nutrients and produce clean energy.

CEDES requested DEA to technically support a project that uses biogas at TECMED. But landfill gas was not within the scope of the current collaboration with Mexico and Denmark has few the state-of-art experts regarding landfills because it is not used anymore in Danish projects.

DEA highly recommends pursuing a biogas collection project at TECMED landfill and also consider the installation of an anaerobic technology for the organic industrial residues that are currently sent to the landfill, such as the residues from Norson, Pegson and ILIS located at the Industrial Park.

2.4. Hermosillo Wastewater Treatment Plant

The Hermosillo WWTP treats all the wastewater that comes from the city of Hermosillo. It is owned by "Agua de Hermosillo" (public). It was built in 2016 by the private company TIAR (Fypasa) and it is being operated by the latter through a contract that will last until 2034.

Hermosillo WWTP has the capacity to treat 2 500 L/s of only municipal wastewater; nevertheless, it has received peaks of organic concentration due to industrial wastewater discharges that does not comply with NOM-002-SEMARNAT-1996, which is very common due to the low pollution fees mentioned before. For instance, the WWTP is designed to receive 320 mg/L of Biochemical Oxygen Demand (BOD), whereas it has received concentration peaks up to 1 000 mg/L BOD.

The wastewater train has the following unit operations until the effluent complies with the NOM-003-SEMARNAT-1996.

- Pretreatment (screening, desander)
- Primary settler
- Completely mixed aerated reactors
- Secondary settler
- UV disinfection

Treated wastewater is currently used used for the irrigation of 950 hectares of whey, garbanzo, sorghum and corn.

Figure 27. Pretreatment, primary settlers, gravity thickeners in Hermosillo WWTP

The treatment and handling of the sludge has the following unit operations before being disposed into the TECMED landfill, about 40 m^3/d of sludge with 22% solids concentration:

- Thickening (gravity thickeners for primary sludge/ belt thickener for secondary sludge)
- **Anaerobic reactors with biogas mixing (2 x 12 000 m^3)**
- Decanter centrifuge

Figure 28. Belt thickener for secondary (biological) sludge in Hermosillo WWTP a) on the top, b) lateral view.

Figure 29. Anaerobic digester and secondary clarifiers in Hermosillo WWTP

Figure 30. Trucks that will transport sludge from Hermosillo WWTP to Tecmed landfill.

It is important to note that it is very unfortunate that the sludge produced at Hermosillo WWTP is being sent to TECMED landfill because this was a requirement in the Terms of Reference of the project, but it could be used as a fertilizer complying with NOM-004-SEMARNAT-2002 (Class C). Nevertheless, TIAR and Agua de Hermosillo are open to the possibility of sending sludge to nearby farms for free.

Biogas treatment has the following unit operations before being burned:

- Gasholder (2 x 2150 m^3, Residence time = 5 hr aprox under design conditions)
- Drying by condensation
- **Cogenerators (3 x 874 kW; arrange designed: 2 in operation + 1 stand-by)**
- Biogas burner.

Figure 31. Roof on anaerobic digester, gasholders, biogas burners and agricultural lands nearby Hermosillo WWTP

Figure 32. Condensate-sediment traps and filters for biogas

Figure 33. Three cogenerators (874kW) in Hermosillo WWTP (new but not operating). A basement for a forth cogenerator is already built.

Unfortunately, the cogenerators are not operating due to two main reasons:

1) **Less biogas production than expected.** The primary clarifier receives a greater amount of sand than was stipulated in the design; therefore, the sand is not being properly retained in the pretreatment which causes it to end up in the primary sludge. As a result, primary sludge is drained and disposed separately to avoid the accumulation of sand in the anaerobic digesters. As a result, anaerobic digesters are producing 180 m^3/h of biogas instead of 830-970 m^3/h which is what was expected in the design.
2) **Bad biogas quality**. Industrial contributions in wastewater have caused H_2S concentrations of up to 5 000 ppm in the biogas, this is not typical of municipal wastewater which is usually between 500 and 1 500 ppm (EnRes 2017). Currently, the WWTP operators add ferric chloride into the anaerobic digester in order to precipitate Sulphur salts; nevertheless, this only reduces H_2S concentration to 4 000 ppm when it needs to reach a maximum concentration of 1 000 ppm in order to be used in cogenerators. Chemical addition is an unexpected additional cost for the operation of the WWTP because “Agua de Hermosillo” pays a fixed amount per m^3 of treated wastewater produced to TIAR.

PROBLEM STATEMENT AT HERMOSILLO WWTP:

Hermosillo WWTP has no problems in complying with wastewater effluents standards, but sludge and biogas trains have attractive opportunities that could reduce the operational cost of the plant. For example:

a) **Pretreatment.** A better system for sands removal should be installed. This would allow to enter primary sludge into the digesters and this would increase biogas production.

b) **Biogas train**. The chemical addition of ferric chloride is expensive and is not enough to achieve the quality required for the use of biogas in the cogenerators. Another technology that can be explored is the biological removal of sulphur such as the BiogasClean equipment. Fypasa has a BiogasClean® installed in León WWTP, where there are similar problems related to the contribution of industrial pollutants in the sewerage. The BiogasClean of Leon WWTP started-up and operates properly (currently in process), this experience can be used in Hermosillo. It is important to mention that in the WWTP design, Fypasa plans to install a fourth cogenerator in the future, so that, two generators could operate continuously, the third one could operate half of the time (during peak tariff) and the one remaining as stand-by. This means that biogas installations (pipes, traps, filters) should be prepared for a future scenario in which three cogenerators operate simultaneously. It is essential to solve the sand issue (in process).

c) **Sludge train**. As the WWTP is surrounded by agricultural lands that already use treated wastewater, it is highly probable that an agreement with the farmers could be negotiated to avoid the economic and environmental cost of transporting the stabilized sludge by 55 km to TECMED landfill where the sludge does not have any use and instead contributes to methane emsissions.

SO.. WHAT TO DO WITH INDUSTRIAL DISCHARGES?

"Agua de Hermosillo" has tried to restrict contributions of liquid effluents from commercial, industrial and private business by collecting them. These residues are transported by vactors into another Industrial WWTP. This is a summary of the residues that are collected in a month in "Agua de Hermosillo":

Table 1. Industrial residues transported to the Industrial WWTP

Type of liquid residue	Volume (m^3/month)
Portable bathrooms	90
Septic tanks	1 222
Grease tramps	418

Part of the treated wastewater is used for irrigation, but "Agua de Hermosillo" considers that the treatment at the Industrial WWTP is not adequate

As a summary, the industrial discharges that enters to Hermosillo WWTP, the industrial residues transported from the Industrial Park to TECMED, as well as the liquid residues collected and transported by "Agua de Hermosillo" into the Industrial WWTP, are currently seen as a problem that is being "controlled" but in reality this is causing economic

and environmental problems and these are the specific reasons: a) the Hermosillo WWTP is not prepared for industrial discharges, b) Landfill does not allow nutrients reuse and has GHG emissions, and c) the Industrial WWTP is not properly treating the effluent.

Hermosillo WWTP currently has anaerobic digesters and biogas facilities ready for a future update. This could allow the establishment of a co-digestion system where a certain amount of industrial residues are pre-treated in order to feed the anaerobic digesters without compromising the operation of the plant.

PROPOSAL FOR PREFEASIBILITY STUDY 3:

Co-digestion of industrial residues at WWTP

3. PRE-FEASIBILITY STUDIES

As a result of the analysis of the sites visited, three potential biogas projects in Hermosillo were selected and evaluated in a pre-feasibility study:

1. **Anaerobic lagoon at pig farms**
2. **UASB at Norson slaughterhouse**
3. **Co-digestion of industrial residues at WWTP**

The following chapters will describe the proposal; make an estimate of the investment, operational costs as well as saving and benefits; and finally, the feasibility of these projects from the economic and environmental point of view is analyzed.

3.1. Pre-feasibility study 1. Anaerobic Lagoon at pig farms

3.1.1. Technical pre-evaluation

3.1.1.1. General train proposed for pig farm slurry treatment

The sedimentation ponds are unnecessary large for treatment purposes. The proposal is to install a complete treatment system that can not only obtain and use biogas, but can also recycle nutrients and water for agricultural purposes.

The following treatment train is proposed:

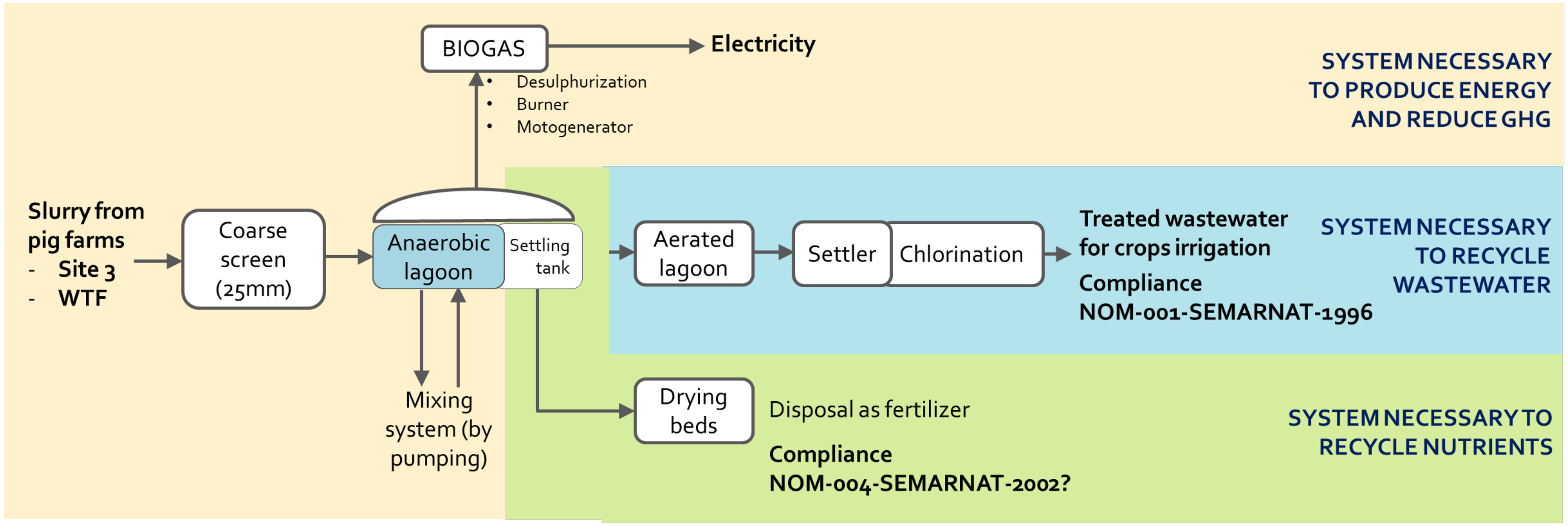


Figure 34. Treatment train for pig manure

3.1.1.2. System needed to produce energy and reduce GHG (Anaerobic)

ANAEROBIC LAGOONS

The slurry coming from a pig farm, preferably WTF or Site 3, may have a coarse screening before entering to an anaerobic lagoon of 60 days of hydraulic retention time (recommended 20-50 days). The proposed anaerobic lagoons would have a depth of 6.0 meters. The anaerobic lagoon may have a mixing system (by intermittent recycling pumping) in order to enhance the efficiency of the anaerobic lagoon, optimize biogas production, and to avoid (as possible) the sedimentation and accumulation of solids in the lagoon. The efficiency of BOD removal in anaerobic lagoons is 50-85%.

ASSUMPTIONS:

The following parameters were recommended by SENER, DEA, IBTech, Clúster de biocombustibles gaseosos and II-UNAM (2018) in order to calculate biogas production and quality from pig manure:

- Methane potential (yield)= 244-343 (300 Nm^3CH_4/ton_{VS})
- Typical methane content in biogas= 47 – 68% (58%)
- Typical sulfur (H_2S) content in biogas= 1.0%
- Production of solids per head in WTF site= 0.313 kg_{VS}/hd/d

ANAEROBIC LAGOON:

The slurry produced in each WTF farm of 12 800 pigs is:

$$VS\ production = (12\ 800\ hd)\left(\frac{0.313\ kgVS}{hd * d}\right) = 4\ 006\,\frac{kgVS}{d}$$

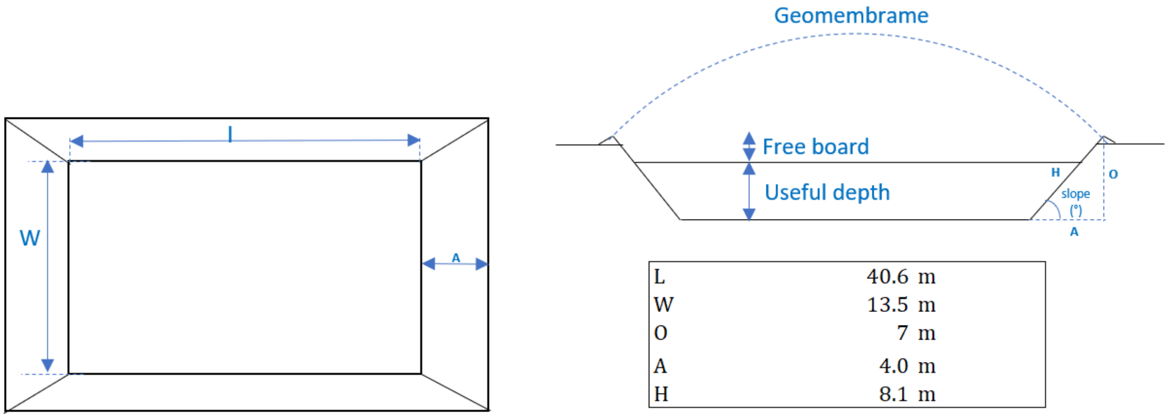
$$Slurry\ production = \left(\frac{4\ 006\ kgVS}{d}\right)\left(\frac{kgTS}{0.67\ kgVS}\right)\left(\frac{m^3}{80\ kgTS}\right) = 75\,\frac{m^3}{d}$$

The configuration of the anaerobic lagoon is:

Table 2. Configuration of the anaerobic lagoon

ANAEROBIC LAGOON (INCLUDES 3 DAY SETTLING POND)		
Total HRT	60	days
Number of lagoons	1	lagoons
Useful volume of each lagoon	**4500**	**m^3**
Useful depth	6	m
Width	13.5	m
Length	40.6	m

Free board	1	m
Slope	60	°
Area requirement (footprint)	1051	m^2
Geomembrane (no covering)	1554	m^2
Geomembrane for covering (15% more due to gas volume)	1209	m^2
Excavation	5505	m^3



L	40.6	m
W	13.5	m
O	7	m
A	4.0	m
H	8.1	m

Figure 35. Treatment train for pig manure

BIOGAS

The effluent from the anaerobic lagoon enters to a settling tank (a compartment inside the lagoon) from where the solids are purged.

Pig production has no continuous heat requirements (specifically WTF and Site 3) and for sanitardy reasons farms are placed far away and not easily accessible. Therefore, the biogas cannot be used in a boiler to produce heat. Fuel production for vehicles has not been assessed in this study, and is only relevant if a fleet of gas driven vehicles are potential customers.

The only reasonable use for biogas is to produce electricity. So, the biogas produced in the anaerobic lagoon and the one that escapes from the settling tank compartment can be collected and transported by pipes to a treatment system. The biogas flow in the pig farm would be 2 072 m^3/d approximately, with 58% of methane, as shown in the following calculations:

$$Methane\ production = \left(\frac{4\ tonVS}{d}\right)\left(\frac{300\ Nm^3CH_4}{tonVS}\right) = 1\ 200\frac{Nm^3CH_4}{d}$$

$$Biogas\ production = \left(\frac{1\ 200\ Nm^3CH_4}{d}\right)\left(\frac{Nm^3biogas}{0.58\ Nm^3CH_4}\right) = 2072\frac{Nm^3biogas}{d}$$

If the biogas is used to produce electricity and the electrical efficiency in the motor generator is 35%:

$$Motogenerator\ capacity = \left(\frac{1200\ Nm^3CH_4}{d}\right)\left(\frac{10\ kWh}{Nm^3CH_4}\right)\left(\frac{1\ d}{24h}\right)(0.35) = \frac{175\ kWh}{h} = \mathbf{175\ kW}$$

The biogas would enter a 175 kW motogenerator in order to produce electricity. Gas holder is not proposed as the experience with anaerobic lagoon shows that the residence time is so large that it is difficult to have peaks of biogas flow. So, the biogas storage that exists in the geomembrane located at the top of the lagoon is enough.

However, before using the biogas, a desulfurization and condensation step is needed. The H_2S content in the biogas that comes from pig manure can vary from 0.4 to 1.0 % (SENER, DEA, IBTech, Clúster de biocombustibles gaseosos, II-UNAM, 2018). This value exceeds the maximum limit to be able to use of biogas in a motogenerator, so it requires a treatment system. In this pre-feasibility study, it was assumed that H_2S concentration is 0.4%, so the proposed technology is iron sponge (ferric oxide filter). Nevertheless, in case of a higher H_2S concentration, the selected technology may change to a biological system, which is more expensive in terms of investment but less expensive in terms of operation (cost per kg of sulphur removed).

The proposed motogenerator would operate 8 000 hours per year - 22 hours per day, almost continuously. The motor-generator also can serve as emergency power supply. The option of a motogenerator that operates only during peak hours is not feasible in this case because:

1) The electricity demand in this place is low (considering not selling electricity to the grid, which is a complicated and expensive option, its regulation is described in Annex 3- Regulations for selling electricity into the grid in Mexico)).
2) The difference between base, intermediate and peak tariff in Mexico is not very high, the ratio is approximately 0.63: 1: 1.11, respectively. A motor generator that only works during peak hours can be an attractive option if the ratio between normal and peak tariff is large enough to make it economically feasible (commonly greater than six).

If the equipment works 8 000 hours per day, approximately 90% of the time, the electricity generated in one pig farm for a year would be:

$$Electricity\ production = \left(\frac{175\ kWh}{h}\right)\left(\frac{8\ 000\ h}{year}\right)\left(\frac{1\ GWh}{1\ 000\ 000\ kWh}\right) = 1.4\frac{GWh}{year}$$

The biogas should be burned when biogas pressure exceeds certain level and motor generator is not operating due to maintenance.

One of the issues, in the 5 pig farms WTF cluster, is that the production of electricity in one farm (175 kW approx.) using biogas, exceeds the electricity consumed at the farm (40 kW approx.).

It is recommended that in the short-term, electricity be supplied to the five (5) farms in the cluster with a single motogenerator and an anaerobic lagoon. In the future, another four (4) motor generators (or just one large motor generator) will be installed if the CFE permits are obtained and/or, subsequent aerated lagoon could be installed in order to treat and recycle the wastewater. Excess of energy could be used for the electricity requirements of the aerated lagoons (30 kW approx.).

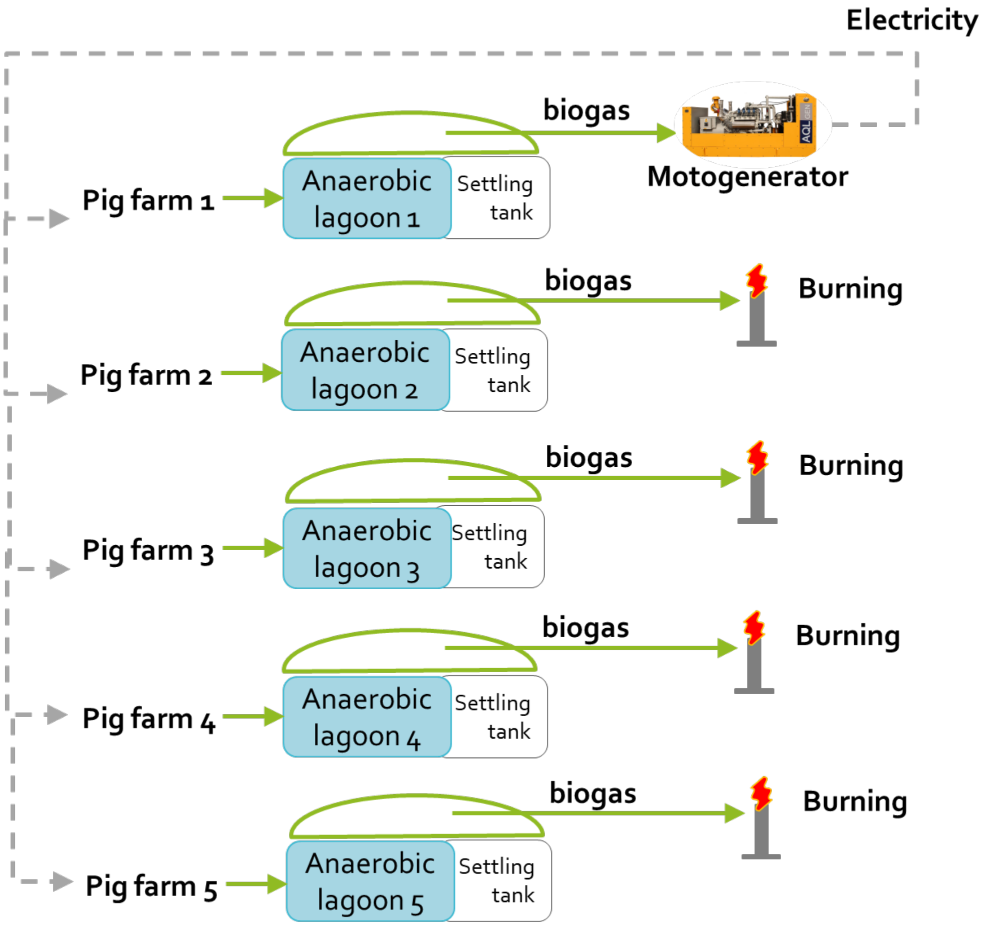


Figure 36. Short term proposal for the WTF Cluster. Electricity for own consumption

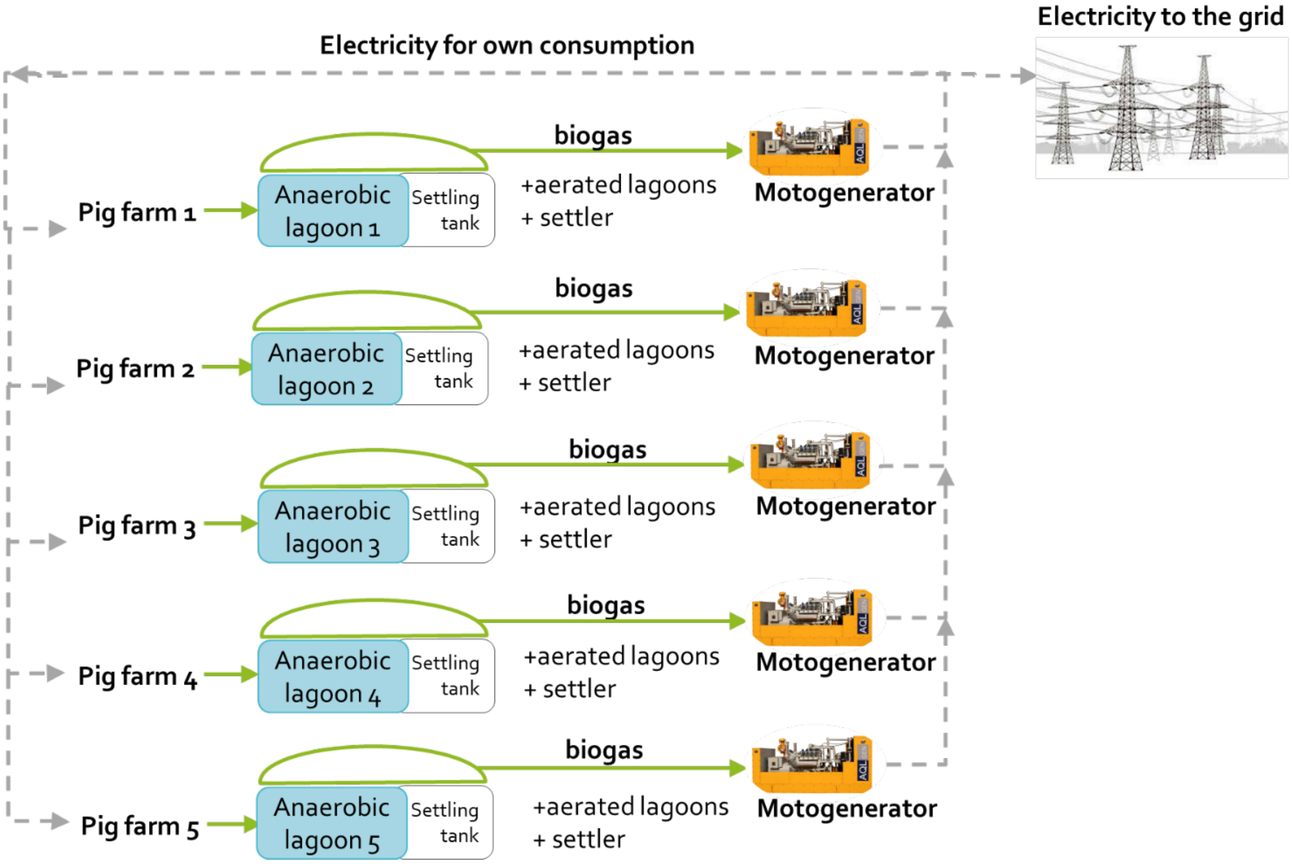


Figure 37. Future scenario for the WTF Cluster. Electricity for own consumption and selling to the grid.

3.1.1.3. System needed to recycle nutrients (Sludge)

The sludge purged from the settling tanks of the anaerobic lagoons will be spread on open drying beds in order to reduce moisture, volume and pathogens, and at the same time facilitate the transport of sludge to agricultural lands.

Drying beds are a commonly used method to dewater sludge via filtration and evaporation. Perforated pipes situated at the bottom of the bed are used to drain seepage water or filtrate. Drying beds can be covered and electro-mechanically operated.

In this case, due to the high availability of nearby land, the low precipitation and great evaporation that occurs in Hermosillo, the drying bed can be simpler: just a concrete space for the sludge to be dried by evaporation without any filtration system nor covering.

Helminth ova, a cause of intestinal parasites are limited in the normativity (see ANNEX 1 – MEXICAN NORMATIVITY REGARDING WASTEWATER AND SLUDGE), would be removed mainly by sedimentation in the sludge. But sedimentation does not necessarily result in the inactivation of pathogens, which may remain viable in sludge and sediments of wastewater stabilization ponds (Verbyla M, et al., 2017).

For this pre-feasibility study, it was assumed that helminth ova are not a problem in the slurry coming from pig farms due to the sanitary regulations at Norson, and that the stabilized sludge can be used if it is classified as “good”, Class C. Nevertheless, if helminth ova are present in high concentrations in the slurry and/or a better quality of sludge is required, it may be necessary to have a further treatment.

These are the cheapest options for sludge treatment if helminth ova presence is a problem in the pig farms and/or if the sludge requires to be upgraded from “Class C” to “Class A” or “Class B” (see ANNEX 1 – MEXICAN NORMATIVITY REGARDING WASTEWATER AND SLUDGE):

- Alkaline post-stabilization (for sludge)

It is an effective method of stabilization, in which faeces are stored for more than 1-2 years with a solids content between 50-60% and bulking agents (lime, soil, leaves, etc.) are added; which are kept at a certain temperature (Jimenez, 2017).

This is widely used to treat sludge in big and small wastewater treatment plants and even in on-site sanitation systems, because of its low capital and operational costs and operational ease. It is useful when large amounts of helminth ova are involved. By adding lime (or any other alkaline material) to dewatered sludge, pH should be raised above 12 for at least 2 h. Lime doses of 20 –40% dry weight may inactivate 0.5 –2 log of helminth ova (Jiménez et al., 2001).

Due to the pH increase (>12) and temperature increase (>57°C), the alkaline stabilisation process achieved Type B biosolids with doses of 15% and 20%, whereas doses of 25–40% produced Type A biosolids (Jiménez, 2001).

- Composting

Process that lasts 2– 4 weeks at a mean temperature of 55.8°C for 4 h. During composting, temperature may reach values as high as 70.8°C that are capable of inactivating helminth ova (Dougherty, 1999).

- Heating (using heat from cogeneration)

It was observed that a thermophilic system for the treatment of pig slurry at 55-70° C rapidly killed the free-living stages of three common pig parasites. This treatment could be beneficially incorporated in any pig slurry recycling process, whether to land or to animals (Burden D.J., Ginnivan M.J., 1978). This is a widely used process in Denmark, but might be too expensive in this case due to the need for accumulation tank and heat exchanger required.

3.1.1.4. System needed to recycle water (aerobic)

The clarified wastewater coming from settling tank enters to a polishing treatment that includes two aerated lagoons of 1 050 m^3 each one, with 3 meters of useful depth, followed by a settler and a chlorination final step (disinfection). The aerated lagoons would have eight (8) superficial aerators installed, that in total may require about 50 HP (40 kW approx.). After aerated lagoons, a final gravity settler and chlorination are necessary before pumping the water to its final use (irrigation). The pumping system (or transportation by water pipes) of the treated wastewater is not included in this study because the location of the final use is unknown.

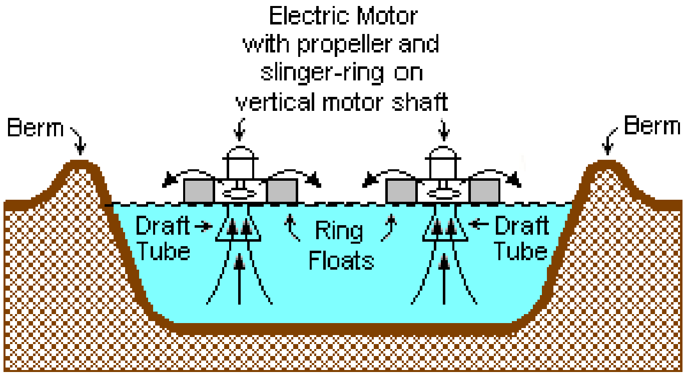
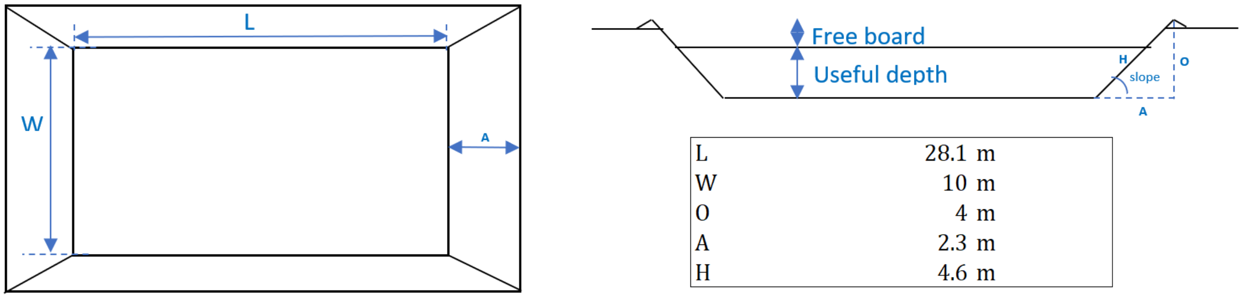


Figure 38. Typical aerated lagoon with surface aerators.

Table 3. Configuration of the aerobic lagoon

AEROBIC LAGOON		
Total HRT	28	days
Number of lagoons	2	lagoons
Useful volume of each lagoon	1 050	m^3
Useful depth	3	m
Width	10	m
Lenght	28.1	m
Fee board	1	m
Slope	60	°
Useful volume of lagoon	**2 100**	m^3
Area requirement	955	m^2
Geomembrane (no covering)	1 350	m^2
Excavation	2 998	m^3



L	28.1	m
W	10	m
O	4	m
A	2.3	m
H	4.6	m

Figure 39. Configuration of each aerated lagoon

As mentioned before, in this pre-feasibility study, it was assumed that helminth ova are not a problem in the slurry coming from pig farms due to the sanitary regulations at Norson. Moreover, waste stabilization ponds are very efficient at removing helminth ova, mainly by the sedimentation process, which requires 5–20 days of retention time. In developing countries with warm climates, the use of stabilization ponds to recycle wastewater for agriculture is recommended when land is available at a reasonable price. (Jimenez B., *et al*., 2007).

However, if helminth ova presence is still a problem in the effluent of the lagoons at the pig farms (see ANNEX 1 – MEXICAN NORMATIVITY REGARDING WASTEWATER AND SLUDGE), sand filtration as a final step could be an option. Rapid filtration removes 90 –99% of helminth ova and may be increased if coagulants are added (Jiménez et al., 2001). Rapid filters have a filtration media size from 0.8 to 1.2 mm, a minimal filter bed of 1 m and filtration rates varying from 7 to 10 m^3/m^2 h. Under these conditions, the effluent constantly contains 0.1 HO/L and the filtration cycles are 20–35 h (Landa et al., 1997).

Also, thermal treatment could be an option, using motor heat.

It is worthy to mention that under other circumstances; the aerated lagoon could have been replaced by much larger aerobic (not aerated) lagoons and constructed wetlands. The disinfection final step could have been replaced for a maturation pond in which the removal of pathogens is done by natural solar radiation. A complete pond treatment system may require larger footprint, but it is cheap, and it does not require electromechanical equipment. Nevertheless, Hermosillo is a very dry and very warm place, the annual average temperature is 24.3°C (normal minimum 16.7°C and normal maximum 31.9°C); the annual precipitation is 305 mm and the annual evaporation is 2 854 mm. Therefore, a natural system like constructed ponds or wetlands -more footprint (area) but no electricity required- may lead to significant reduction of treated water; approximately 70% of treated wastewater can be lost due to evaporation. Interestingly, despite Sonora is a very dry place, its soil is suitable for crops agriculture, so water is a very valuable resource.

3.1.2. Economical pre-evaluation

ASSUMPTIONS:

- The prices shown are preliminar estimations for the short-term proposal (one motogenerator for the cluster)
- Electricity cost: **$2.3/kWh** (intermediate tariff at Hermosillo for medium tension, industrial purposes, price according to Norson).
- **No heat recovery** considered because no feasible use in the site.
- Exchange rate: MX$19/USD
- Prices given does not include taxes (VAT 16%)

3.1.2.1. CAPEX

a) Saving costs for the installation of the new lagoons

The comparison between the existing system and the proposed one showed that there would be saving costs of investment regarding geomembrane and excavations as the proposed system requires about 66% less geomembrane and 85% less excavation than the existing sedimentation ponds, as shown in table 4:

Table 4. Configuration of the aerobic lagoon

PER PIG FARM		EXISTING*	PROPOSED	SAVINGS
		2 Sedimentation ponds of 1-2 years HRT	Anaerobic + Settler + Aerated lagoon + Settler + Chlorination	
Useful volume	m^3	44 000	6 825	84%
Area requirement	m^2	11 199	2 192	80%
Geomembrane	m^2	12 768	4 363	66%
Excavation	m^3	60 064	8 886	85%

Note*: The calculations of the existing system do not include the evaporation lagoon (volume unknown), just the sedimentation ones.

Consequently, all the costs related to excavation, geomembrane, geotextile, welding, mechanical fixation of membrane, transportation of materials, manpower for the installation of the lagoon, and the road access to the site are not included in the investment cost. It is assumed that the resources that Norson already spends in the construction of the sedimentation and evaporation ponds are more than enough to cover the corresponding expenses for the proposed lagoons for new sites. Moreover, it is highly probable that Norson has a saving costs (due to less excavation and geomembrane) that must be considered in a further and more detailed economical evaluation.

Just as a reference, according to Norson, the cost of the settling ponds is about USD 3.46/m^3 (cheap). So, they should have spent two sedimentation ponds installed per farm (not considering the evaporation pond) = (22 000 m^3) x (2 lagoons) x (USD 3.46/m^3) = USD 152 240 approximately.

b) Electromechanical equipment estimation

Table 5. Estimation of costs of electromechanical equipment

PRETREATMENT	COST

	- Coarse screen 25mm, stainless steel - Platter for solids, stainless steel - Security perimeter handrail, carbon steel Ced. 30 1-1/2" D - Manual hoist for 0.5ton	$8 841
ANAEROBIC LAGOON 4500 m^3		
	- Geomembrane poliethilene and thermal fusion - Materials for mechanical fixation of geomembrane at the perimeter. - Waterproofing of geomembrane cell	$0
	- Corrugated pipe for biogas capture and transportation - Relief pipe over covering	$5 436
MIXING SYSTEM AND SLUDGE PUMPING		
	- Two centrifuge pump and installation accessories, 10 HP, 18 L/s @ 1kg/cm^2 discharge pressure.	$6 545
	- Level meter - Valves (butterfly and check) 3in diameter - Pipes, flanges and interconnection accessories of 3 in carbon steel ASTM A Ced. 40.	$20 214
BIOGAS DESULPHURIZATION		
	Iron filter	$6 574
BURNER		
	- Biogas burner and security accessories of 2" diameter for 2 800 m^3/d of biogas.	$54 043
MOTOGENERATOR		
	- Motogenerator of 175kW, brand "Ambar". - Corrugated pipe for biogas	$381 805
ANAEROBIC	**TOTAL SUPPLY AND INSTALLATION OF ELECTROMECHANICAL EQUIPMENT FOR THE SYSTEM NECESSARY TO PRODUCE ENERGY AND REDUCE GHG**	$483 458
INTERNAL ANAEROBIC SETTLER		
	- Two submersible pumps 5 HP, 12 L/s @ 1kg/cm^2 discharge pressure.	$9 673
	- Level meter pear type of mercury - Valves (butterfly and check) 3in diameter - Pipes, flanges and interconnection accessories of 3in carbon steel ASTM A Ced. 40.	$28 520
SLUDGE	**TOTAL SUPPLY AND INSTALLATION OF ELECTROMECHANICAL EQUIPMENT FOR SYSTEM NECESSARY TO RECYCLE NUTRIENTS**	**$38 193**
FOR RECYCLING WASTEWATER FOR IRRIGATION		
AERATED LAGOON (2 X 1 050 m^3)		
	- Geomembrane polyethylene and thermal fusion - Materials for mechanical fixation of geomembrane at the perimeter. - Waterproofing of geomembrane cell	$0
	- Eight (8) surface aerators (Aeromix), 5 HP each one - Steel wire	$104 984
SETTLING LAGOON 225 m^3		
	- Excavation - Geomembrane polyethylene and thermal fusion - Materials for mechanical fixation of geomembrane at the perimeter. - Waterproofing of geomembrane cell	$0
CHLORINATION		
	- Dosing pumping system of sodium hypochlorite	$4 500

AEROBIC	**TOTAL SUPPLY AND INSTALLATION OF ELECTROMECHANICAL EQUIPMENT FOR SYSTEM NECESSARY TO RECYCLE WASTEWATER**	**$109 484**

c) Total investment costs

The description and scope of each item in the table below, related to the CAPEX costs, is described in ANNEX 4 – CAPEX AND OPEX (ITEMS DEFINITIONS).

Table 6. Summary of total investment costs

INVESTMENT	ANAEROBIC	SLUDGE	AEROBIC	TOTAL
DESCRIPTION	**USD**	**USD**	**USD**	**USD**
Electromechanical equipment	$483 458	$38 193	$109 484	$631 135
Civil works and structures(1)	$14 504	$16 795	$6 569	$37 868
Electrical installation	$53 180	$4 201	$12 043	$69 425
Piping and mechanical installation	$22 239	$1 757	$5 036	$29 032
Engineering Project	$42 000	$0	$0	$42 000
Start-up	$22 000	$0	$0	$22 000
TOTAL	$637 381	$60 946	$133 133	$831 460

Notes:
1. Costs related to excavations, machinery for soil transport, road access to the plant are not included, as they would have to be paid in all cases.

3.1.2.2. OPEX

For the OPEX costs, the general assumptions for all the pre-feasibility studies are described in ANNEX 4 – CAPEX AND OPEX (ITEMS DEFINITIONS).

Table 7. Operating costs

OPERATING COSTS	ANAEROBIC	SLUDGE	AEROBIC	TOTAL
FIXED COSTS	**USD/year**	**USD/year**	**USD/year**	**USD/year**
Personnel	$22 749	$0	$0	$22 749
Laboratory	$600	$600	$600	$1 800
Maintenance	$30 240	$2 376	$6 830	$39 446
SUBTOTAL FIXED COSTS	**$53 589**	**$2 976**	**$7 430**	**$63 994**
VARIABLE COSTS	**USD/year**	**USD/year**	**USD/year**	**USD/year**
Biosolids transportation	$0	$2 520	$0	$2 520(1)
Biosolids disposal	$0	$0	$0	$0(2)
Chemical reagents/ Biogas treatment	$11 406(3)	$0	$1 763(4)	$13 169
Electrical power	$9 805	$1 944	$31 200	$42 949(5)
SUBTOTAL VARIABLE COSTS	**$21 211**	$4 464	**$32 963**	$58 638
TOTAL OPEX	**$74 800**	$7 440	**$40 392**	$122 632

Notes:
1. MX$ 250/ton was assumed for transportation costs, although the location of the agricultural site is unknown in which this sludge could be used and if, the farmers can take over the transportation costs.
2. No disposal costs are assumed.
3. Cost of the replacement of iron sponge for biogas treatment. No other chemical addition is included.
4. Sodium hypochlorite 13% dosing was assumed for disinfection.

5. This amount corresponds to the electricity consumption of the electromechanical equipment install. The electricity consumption in the anaerobic system is 10 kW approximately (mixing system in anaerobic lagoons), in the sludge system is less than 2 kW (sludge pumping out), and in the aerobic system is 40 kW (surface aerators).

3.1.2.3. Revenues/savings

The project would have some saving costs due to the production of energy for self-consumption. The related calculations are shown in Table 8:

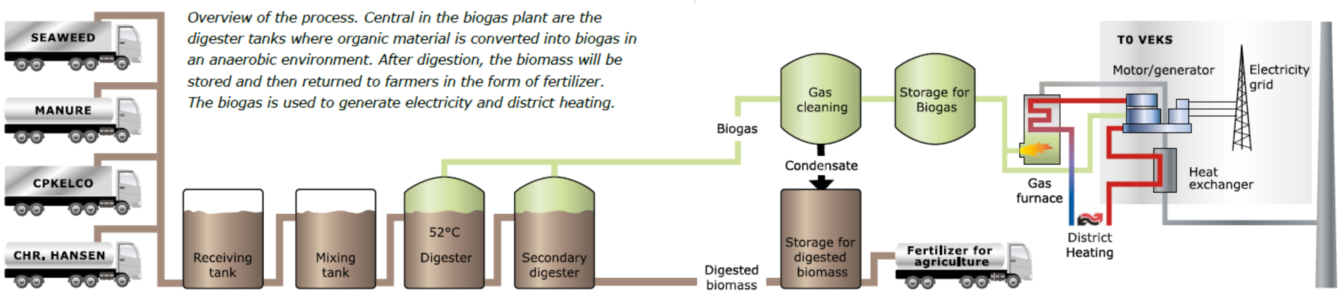
Table 8. Electricity savings

ELECTRICITY		
Motogenerator	kW	175
Operation hours	h/year	8 000
Electricty production	kWh/year	1 400 000
Electricity cost	$/Kw	**2.3**
Electricity savings at pig farms	**USD/year**	**$ 169 233**

At the end, the surplus electricity from an anaerobic system with motogenerator in one farm of 12 800 pigs is 165 kW approximately; but if a sludge dewatering and an aerated lagoon are installed the surplus electricity may be reduced from 165 to 123 kW.

Another saving cost that should be included in the future is the diesel for the diesel generator that is operated when no electricity is available on site. In order to estimate this saving cost, it is necessary to know the historical consumption of diesel, the number of hours per year that the farms need to operate the diesel generator due to lack of electricity.

In Denmark, the pig farms do not separate solids from liquids after anaerobic digestion. At Danish plants, the digestate is just stored and transported directly to the fields. The treated slurry is brought out on fields during the spring, and the harvesting season is 3 – 5 months later. Some examples of the Danish plants that handle liquid biofertilizer as a subproduct are Horsens Bioenergi, Kroghsminde, Madsen Bioenergi, and Solrød biogas. The datasheets of these plants were elaborated under this Programme and are freely available (DEA and SENER, 2019).



Overview of the process. Central in the biogas plant are the digester tanks where organic material is converted into biogas in an anaerobic environment. After digestion, the biomass will be stored and then returned to farmers in the form of fertilizer. The biogas is used to generate electricity and district heating.

Figure 40. Example of liquid fertilizer handling at Solrød biogas plant (DEA and SENER, 2019).

If the digestate was handled as a liquid and the anaerobic system was the only part of the project installed, the payback of the investment would be less than 6.7 years.

3.1.2.4. Payback period

The calculations of the payback period are shown in Table 9. These figures do not consider inflation rates or interests related to bank loans.

Table 9. Financial summary

		ANAEROBIC AND BIOGAS SYSTEM
CAPEX	USD	$637 381
OPEX	USD/year	$74 800
Incomes (savings)	USD/year	$169 233
PAYBACK PERIOD	**Years**	**6.7**

NORSON stated that the total estimated consumption of electricity in the five (5) pig farms of the Wean-to-Finish (WTF) cluster is about 184 kW. This means that the production of electricity in just one farm would cover between 67% and 90% the electricity of the 5-WTF cluster. This would give an energetic self-sustainability to the cluster.

But what would happen in the future if the anaerobic treatment and production of electricity is installed in the five WTF farms in the cluster?

Under this scenario, there would be a surplus of electricity of at least:

$$\left(\frac{123\ kWexcess}{1\ pigfarm}\right)\left(\frac{5\ pig\ farm}{WTF-Cluster}\right)-\frac{184kW\ consumed}{WTF\ \ Cluster}=431\frac{kWsurplus}{WTF\ Cluster}$$

According to the Electric Industry Law, the plants that generates 500 kW of electricity or more, and intends to deliver it to the grid system, requires to pay a network study, a permit and an installation (Cámara de Diputados del H. Congreso de la Unión, 2014) that in summary costs at least USD 42 255 (CENACE, 2015). If it is clean energy, the generator plant can sell Clean Energy Certificated (CELs) at the market electricity price. The problem found along the visits regarding connection to the grid are:

- The applicable law for projects that has a production of electricity less than 500 kW is not clear.
- The cost and the procedures to sell electricity to the grid is very expensive, and complicated.

Due to governmental changes in 2018, the tendering for CELs has been suspended for the moment (Excélsior, 04/12/2018).

3.1.3. Collateral benefits

3.1.3.1. GHG Reduction

ASUMPTIONS:

- The GHG reduction in a pig farm project may come from:
    - Clean energy (electricity) production in the motogenerator.
    - Methane emissions avoided at pig farms (currently, the sedimentation ponds liberate freely the methane produced). The aerobic degradation of organic matter was neglected in this calculation due to the high concentration of slurry and the considerable depth of the existing ponds (5 m).
- Electrical emission factor is 0.582 ton$_{CO2}$/MWh (CRE, 2017)
- Emissions methane equivalence is 28 kg$_{CO2eqq}$/kg$_{CH4}$ (SEMARNAT, 2016).
- Methane density at normal conditions is 0.656 kg/m^3
- Calculations:

Table 10. GHG Reductions

GHG reduction due to clean energy		
Emission Factor	0.582	ton$_{CO2}$/MWh
Electric generation	1 398 011	kWh/year
GHG reduction	814	ton$_{CO2}$/year

GHG reduction due to methane emissions avoided at pig farms		
Methane generation	438 596	m^3$_{CH4}$/year
Methane density	0.656	kg/m^3
Emissions methane equivalence	28	kgCO$_{2eqq}$/kg$_{CH4}$
GHG emissions avoided	8 056	ton$_{CO2}$/year

TOTAL GHG emissions avoided	**8 870**	**ton$_{CO2}$/year**
CAPEX- Investment cost of anaerobic system	637 381	USD
OPEX- Operation cost of anaerobic system	74 800	USD/year
Cost after ten years*	1 385 381	USD after 10 years
GHG avoided after ten years	88 700	ton $_{CO2}$ after 10 years
Cost per m^3 avoided GHG	**15.6**	**USD/ton $_{CO2}$**

Year	**CAPEX (USD)**	**OPEX (USD)**	**INCOMES (USD)**	**ANUAL EXPENSES (USD)**	**ACCUMULATED ANNUAL EXPENSES (USD)**	**ACCUMULATED REDUCTION OF GHG (TON $_{CO2}$)**	**COST PER M^3 OF AVOIDED GHG (USD/ TON $_{CO2}$)**
0	$637,381	$0	$0	$637 381	$637 381	0	-
1	$0	$74 800	$169 233	-$94 433	$542 948	8 870	$61.2
2	$0	$74 800	$169 233	-$94 433	$448 516	17 740	$25.3
3	$0	$74 800	$169 233	-$94 433	$354 083	26 609	$13.3

4	$0	$74 800	$169 233	-$94 433	$259 650	35 479	$7.3
5	$0	$74 800	$169 233	-$94 433	$165 217	44 349	$3.7
6	$0	$74 800	$169 233	-$94 433	$70 785	53 219	$1.3
7	$0	$74 800	$169 233	-$94 433	-$23 648	62 088	-$0.4
8	$0	$74 800	$169 233	-$94 433	-$118 081	70 958	-$1.7
9	$0	$74 800	$169 233	-$94 433	-$212 514	79 828	-$2.7
10	$0	$74 800	$169 233	-$94 433	-$306 947	88 698	-$3.5

The cost per m3 of avoided GHG depends on the stage of the project. The first year, it costs up to USD 61.2/ton$_{CO2}$, but after 6.7 years the cost of the project have been recovered and so, there are not costs related to avoiding GHG emissions, on the contrary, there are revenues.

3.1.3.2. Nitrogen recycle

ASUMPTIONS:

- Nitrogen content in pig slurry is 8% from total solids (CRE, 2017). The nitrogen considered in these calculations is the total amount contained in the slurry, which would be disposed in the treated sludge (60% of total nitrogen approximately) and in the wastewater effluent (the 40% of nitrogen remaining). Nitrification/denitrification processes if aerobic treatment is installed was neglected.

Table 11. Nitrogen recycle calculations

Nitrogen recycle calculations		
Feedstock quantity	28 163	ton/year
Solids concentration	8	%TS
Nitrogen content in TS	70	kg$_N$/ton$_{TS}$
Nitrogen equivalence per year	**158**	**ton$_N$/year**
N content in urea	0.47	kgN/kg_urea
Urea molecule equivalent	**338**	**tons/year**
% purity fertilizer	44%	
Urea fertilizer equivalent	**768**	**tons/year**
Cost of urea fertilizer	7000	MX$/ton
Price equivalence	**$ 282,980**	**USD$/year**

3.1.4. Conclusions

3.1.4.1. Key figures

For the anaerobic and biogas system for a Norson farm of 12 800 pigs-WTF type:

- The investment cost is less than USD 637 381
- The payback period is less than 6.7 years
- The electricity production is 175 kW.
- The GHG reduction is 8 870 ton/year.
- The nitrogen recycle as nutrient is 158 ton_N/year.

The economic feasibility of this project should be better than the figures shown above because it is still pending to consider saving costs due to less excavation and less geomembrane requirements. These costs should be calculated and deducted from the investment costs calculated before.

The investment costs of the subsequent treatment of sludge and water is approximately USD 60 946 and USD 133 133, respectively. These costs can be saved if the digestate were applied directly as liquid fertilizer. This is a common practice in Denmark, although in Mexico there is no legislative framework that allows this practice. The existing norms (NOMs) in Mexico allow the reuse of treated wastewater for irrigation if it complies with a strict quality. And the project of the new norm is stricter indeed (<120 ppm TSS, PROY-NOM-001-SEMARNAT-2017). Regarding the use of sludge as fertilizer, NOM-004-SEMARNAT-2002 establishes the limits in terms of pathogens, but also in terms of solids concentration, which must be at least 15%. The digestate can contain between 2-6% of TSS, so the existing norm does not allow the use of the digestate in any case. The existing legislation framework is demanding sludge-water phases separation, a further treatment of the wastewater and a further dewatering of the sludge, despite both (sludge and water) in some cases may be transported to the same agricultural lands.

3.1.4.2. SWOT analysis

Table 12. SWOT Analysis

STRENGTHS **What are the main reasons for choosing this site?**	**WEAKNESSES** **What are the main reasons for not choosing this?**
- Large amount of disposable substrate: 89 farms nearby (around 10 km radius) producing slurry, they work very poorly and emit methane that is not captured. - When the lagoons are filled the dried manure just stay there, the nutrients are not recirculated, and a new lagoon is build using new land. There might be a need for a new manure treatment in the long run. - Irrigated crop land not so far away, where the digestate can be used instead of mineral fertilizer.	- There is no correlation between production of biomass and energy need: The farms that are not energy demanding (finishers) are the ones that may produce more slurry. On the contrary, the farms that are more energy demanding produce less slurry. - The connection to the electricity grid in order to sell the surplus energy is not clear, costly and complicated.

- Low cost available land. - Norson seems aware and willing to invest if the project is economical feasible for them and/or gives them an environmentally friendly label that represents a competitive advantage**.**	
OPPORTUNITIES - **How can strengths be used and weaknesses be overcome?**	**THREATS** - **What are the main risks related to a project at this site?**
- The biogas project between farms and agricultural areas can be more integrated. The energy can feed the electricity grid; the treated water and the digestate can be used in the nearby agricultural areas. - Collateral benefits (reuse of nutrients and reduction of GHG) are very attractive. - The digestate, potentially, can be used as a fertilizer because poultry manure will not be available in the future (Bachoco is moving to another state).	- Irrigation norms for the agricultural lands nearby could be very strict (especially due to exportation quality limits). - Helminth ova pollution in slurry must be assessed. If this is the case, the treatment should be adapted to inactivate helminth eggs. - Social acceptance in the farms to use treated wastewater and digestate.

3.1.4.3. Lessons learned

- **SLUDGE NORMATIVIY RESTRICTIONS**. If NOM-004-SEMARNAT-2002 (for the use of sludge as fertilizer) does not states a minimum solids requirement, it would be easy to use digestate as a liquid fertilizer like in Denmark and other European countries.
- **INTECONNECTION TO THE GRID.** Connectivity to the grid and sell of CELs is costly, complicated, and not clear for energy project with less than 500 kW surplus.
- **PUBLIC ACCEPTANCE OF SLUDGE FROM PIG FARMS' DIGESTERS.** Public acceptance of sludge from pig farms is low, maybe due to helminth ova problem with wastewater.

3.1.4.4. Following steps

- It should be explored the possibility of obtaining a "special discharge permit" in order to use the digestate directly in the agricultural lands.
- A complete characterization campaign of the slurry is necessary, mainly in order to a) dimension the biological reactors, b) confirm the biogas treatment technology required depending on sulphur concentration, and c) confirm the need for robust removal or inactivation of helminth ova in the treatment plant.
- Nutrient recycling should be completed with an estimation of phosphorus recovery.
- It is important to calculate the difference in investment costs between the existing system (the sedimentation and the evaporation ponds) and the proposed system. At the end, this cost should be deducted from the CAPEX cost in this evaluation.
- In order to estimate diesel saving cost, it is necessary to know the historical consumption of diesel, the number of hours per year that the farms need to operate the diesel generator due to lack of electricity, and the price of the diesel on site.
- Final quotations from suppliers, manufacturers and contractors must be compiled and used for the economic analysis.
- It is recommendable to figure out if there is the market for treated wastewater use. The same analysis should be done for the sludge use; it is indispensable to determine if it is required to get a better Class of sludge (Class B or C). Also, this information is needed in order to calculate and estimate the transportation costs of these by-products.
- Further analysis of selling electricity to the grid and obtaining CELs under the future scenario, in which production of biogas would occur at the five (5) WTF sites instead of just one.

3.2. Prefeasibility study 2. UASB at Norson slaughterhouse

3.2.1. Technical pre-evaluation

3.2.1.1. General train proposed

As described in Chapter 2.2.1, Norson is currently paying a fee in order to discharge into the sewerage, and another fee when wastewater does not comply with NOM-002-SEMARNAT-1997 (See ANNEX 1 – MEXICAN NORMATIVITY REGARDING WASTEWATER AND SLUDGE). The pollution fee is very low, but there is an opportunity to use the industrial wastewater for energy production at the slaughterhouse.

Norson has already installed grease traps, an equalization tank and a Dissolved Air Flotation (DAF) system in order to reduce the concentration of pollutants in the wastewater before discharging into the sewerage. The proposal is to install an Upflow Anaerobic Sludge Blanket (UASB) reactor downstream the existing facility, as shown in Figure 41.

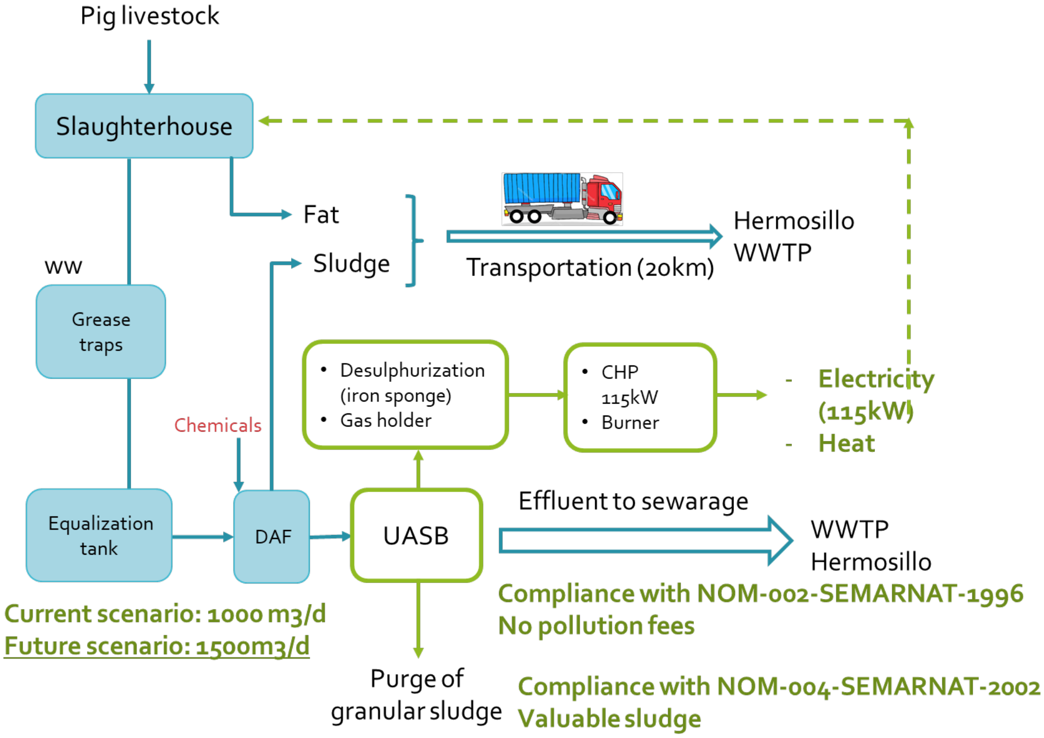


Figure 41. Proposed treatment at Norson slaughterhouse.

The UASB reactor (Upflow Anaerobic Sludge Blanket) has been extensively used in Europe, Asia and Latin America, especially in Brazil. In Mexico, there are 20 plants for industrial water treatment.

In a UASB reactor, wastewater enters the reactor from the bottom and flows upward. A suspended sludge blanket filters and treats the wastewater as it flows through the blanket (Figure 42). Due to metabolism of the microorganisms involved, anaerobic processes do not demand oxygen (electrical consumption for aeration is not required). Besides, a smallest amount of sludge is generated in the water treatment system, and a by-product with high added value is obtained: biogas, capable of being used for energy generation. The purged sludge is also a valuable by-product, it can be sold as a granular sludge for inoculation.

The UASB is particularly suitable for treating industrial wastewater with high concentration of biodegradable organic matter. Among the diverse anaerobic technologies for wastewater treatment, the UASB reactor has the highest acceptance due to the lower investment costs and its compact facilities.

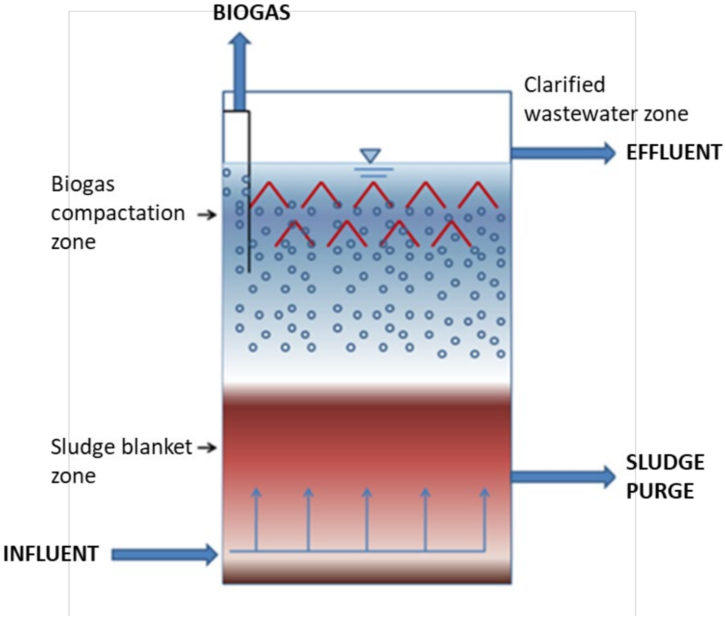


Figure 42. Scheme of UASB.

The concentration of pollutants reported from a composite sample from the final discharge at NORSON Slaughterhouse, done in September 28th, 2017 (see ANNEX 7 – CHARACTERIZATION IN NORSON) is shown in Table 13:

Table 13. Characterization assumed at the entrance of the proposed UASB (lab report 28/sep/2017)

Parameter	Unit	Average value	Range
Simple samples			
Temperature	°C	30	29-30
Floating material		Absence	Absence
pH		7.2	6.5-7.4
FOGs	mg/L	17	8-44
Composite samples			
BOD5	mg/L	620	
TSS	190	190	
Sedimentable solids	mL/L	<0.3	

The UASB produces more biogas, and in consequence more energy, when wastewater is more concentrated. Nevertheless, granular sludge can be affected due to the presence of fats and oils (FOGs). For this reason, it is important to operate the installed DAF system upstream, which removes solids and FOGs content. However, it is recommendable to carry out jar tests in order to determine the optimum chemical and its dosage. It is enough to reduce FOGs below 100 mg/L. Currently, it seems that Norson chemicals dosage is more than required. Reduction in the OPEX costs due to less chemical dosing should be included in a more detailed further evaluation.

Effluent from UASB would be discharged into the municipal sewerage. It is highly probable that it complies with NOM-002-SEMARNAT-1997 in terms of BOD, TSS, temperature and pH. However, it is important to confirm its compliance by carrying out a full characterization, there are also limits in terms of heavy metals (see ANNEX 1 – MEXICAN NORMATIVITY REGARDING WASTEWATER AND SLUDGE.), which concentration is unknown.

Sludge from UASB should be purged every month and can be used to inoculate other UASB reactors in the region (probably installed at other industries nearby). In fact, some companies sell the sludge to others that required granular sludge. If this is not possible, it is highly probable that this granular sludge complies NOM-004-SEMARNAT-1997 Class C after a dewatering and drying step, so it is not necessary to dispose it into a landfill, it can be used indirectly for soil improvement. Again, this compliance depends on the concentration of heavy metals in wastewater, which is unknown yet.

The calculation of the UASB volume is shown as follows:

ASSUMPTIONS:

- Flow (current): 1 000 m^3/d
- Flow (future scenario): 1 500 m^3/d (DESIGN)
- Concentration of BOD: 770 mg/L
- Concentration of COD: 2 150 mg/L= 2.15 kg/m^3
- Organic load: 8 $kg_{COD}/m^3/d$

UASB VOLUME:

According to the design basis, the total volume of the UASB would be:

$$V = \left(\frac{1\,500\ m^3}{d}\right)\left(\frac{2.15\ kgCOD}{m^3}\right)\left(\frac{m3 * d}{8\ kgCOD}\right) = 403\ m^3$$

The proposal is to install two (2) UASB of 200 m^3 each.

3.2.1.2. Use of biogas

There are multiple energy requirements at Norson slaughterhouse: electricity, natural gas for heating, and vehicles fuel.

Although vehicles fuel is an attractive option (diesel price is higher than other fuels), it was not considered a feasible option at the moment due to: 1) the high investment cost of upgrading biogas into biomethane, in order to replace diesel and, 2) the vehicles should be mechanically adapted to receive biomethane as a fuel (more investment costs) and/or the new vehicles should be purchased for using gas.

Regarding substitution of natural gas for biogas, it is worthy to mention that the price of natural gas changes significantly in Mexico. This country imports natural gas from EUA. In 2017, the price was released to the free market so there is no certainty about the price in the future. This framework does not allow to install an energy project for natural gas replacement with a high level of certainty. Moreover, the prices of natural gas during the last years has been low, as shown in Figure 43.

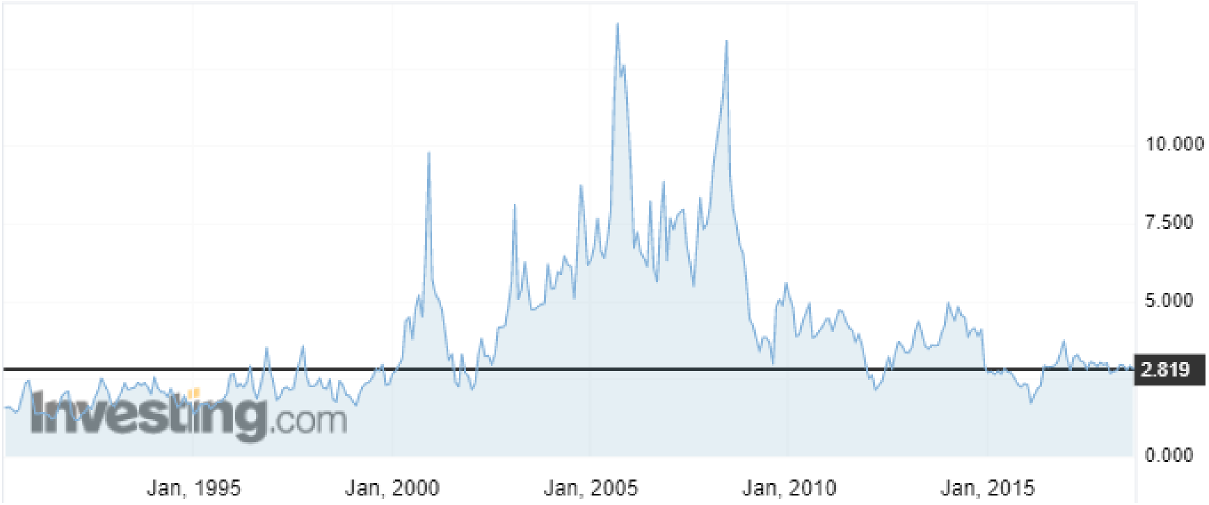


Figure 43. Graph that shows the price of natural gas in the last 10 years (http://mx.investing.com/)

For this reason, it was decided to propose the use of biogas in a **combined heat and power** (CHP) equipment, in which there is simultaneous production of electricity and heat, which is recovered and utilised later.

The H_2S content in the biogas that comes from red stream in a slaughterhouse is commonly less than 0.1 % (SENER, DEA, IBTech, Clúster de biocombustibles gaseosos, II-UNAM, 2018). This value exceeds the maximum limit recommended for use of biogas in a CHP, which is usually 500ppm. Therefore, the biogas requires a desulfurization step upstream the CHP. The proposed technology is iron sponge.

As a reminder, in Chapter 2.2.1, it was mentioned that the operation of the slaughterhouse of the plant is done 14 hours per day, 5.6 days per week. The equalization tank and the gas holder would help to buffer the biogas production and ease its constant use during business days, but it is likely that during weekends, when the slaughterhouse is not operating, the CHP would not operate either. As a result, the CHP would operate during approximately:

$$CHP\ operation = \left(\frac{52\ weeks}{year}\right)\left(\frac{5.6\ days}{week}\right)\left(\frac{24 hours}{day}\right) = 6\ 989\ \frac{hours}{year}$$

As mentioned before in Chapter 3.1.1.2., the option of a CHP that would operate just during peak hours tariff is not feasible in Mexico, as the difference between peak hour tariff and low/medium tariff is not big enough.

ASSUMPTIONS:

- For methane and energy production calculations:
  - Methane generation factor= 0.35 m^3CH_4/kg_{COD} removed
  - Efficiency of COD removal in UASB= 70% (conservative)
  - Energy factor= 10 kWh/ m^3CH_4
  - Hours of operation of CHP= 6 989 hours per year
- For electricity production:
  - Electrical efficiency of CHP= 35%
- For heat production:
  - Heat efficiency of CHP= 50%
  - Natural gas heat value= 8.8 kWh/Nm^3
  - Heat exchanger efficiency= 90%
  - Heat losses during transportation of heat from WWTP to plant= 10%

ENERGY PRODUCTION:

The methane production would be:

$$Q_{biogas} = \left(\frac{1\,500\,m^3}{d}\right)\left(\frac{2.15\,kgCOD}{m^3}\right)(0.70ef)\left(\frac{0.35m^3CH_4}{kgCOD}\right) = 790\frac{m^3CH_4}{d}$$

The energy content in biogas would be:

$$Energy_{biogas} = \left(\frac{790\ \ m^3CH_4}{d}\right)\left(\frac{10\,kWh}{m^3CH_4}\right)\left(\frac{1\,d}{24h}\right) = 329\frac{kWh}{h} = 329\,kW\,energy$$

The electric capacity of the CHP would be:

$$CHP = (329\,kW)(0.35) = 115\,kW\,electricity$$

The production of electricity per year would be:

$$Electricity = \left(\frac{115\,kWh}{h}\right)\left(\frac{6\,989\,h}{year}\right)\left(\frac{1\,GW}{1\,000\,000\,kW}\right) = 0.8\frac{GW}{year}$$

The heat recovery could replace natural gas:

$$Heat = \left(\frac{329\,kWh}{h}\right)\left(\frac{6\,989\,h}{year}\right)(0.5)(0.9)(1-0.1)\left(\frac{m^3natural\ gas}{8.8\,kWh}\right) = 105\,035\ \frac{m^3natural\ gas}{year}$$

3.2.2. Economical pre-evaluation

ASSUMPTIONS:

- The prices shown are preliminary estimations that must be confirmed in a further more detailed evaluation.
- Electricity cost: MX**$2.3/kWh** (intermediate rate at Hermosillo for medium tension, industrial purposes, price according to NORSON).
- **Natural gas price: MX$5/m^3**
- Exchange rate: MX$19/USD
- Prices given does not include taxes (VAT 16%)

3.2.2.1. CAPEX

The cost estimation assumes that the system required in the future is 2x 200m^3 UASB reactors and a CHP equipment. No cost for pre-treatment, sludge drying or access to the site is included.

The estimated package cost of 2 x 200m^3 UASB reactors is USD$ 308 055; it includes structure, primary box, recirculation pump, recirculation pump hoist, collection gutters and bell system.

Other electromechanical equipment needed is described in Table 14.

Table 14. Estimation of costs of electromechanical equipment

Electromechanical equiment	Cost (USD$)
Gas holder of 200m^3 (4hr residence time aprox). It includes outer and inner layers, gas-tight membrane and interface board and connections.	$ 58 443
Biogas burner. It includes accessories (pressure and vacuum assembly relief with flame arrester, check valve, drip traps).	$ 54 043
Desulfurization. Ferric oxide filter	$6 574
CHP of 115kW electrical energy outlet and corrugated pipe for biogas	$ 296 781
TOTAL	**$ 415 841**

a) Total investment costs

The description and scope of each item of the table below, related to the CAPEX costs, is described in ANNEX 4 – CAPEX AND OPEX (ITEMS DEFINITIONS). The summary of the total investment costs is shown in Table 15.

Table 15. Summary of total investment costs

INVESTMENT		**TOTAL**
DESCRIPTION		**USD**
UASB reactors (package cost, it includes civil, mechanical and piping works)		$ 308 055
For biogas holder, burner, desulfurization, and CHP	Electromechanical equipment	$ 415 841
	Civil works and estructures	$ 24 950
	Electrical installation	$ 45 743
	Piping and mechanical installation	$ 19 129
Engineering Project		$ 50 673
Start-up and comissioning		$ 18 000
TOTAL		**$ 882 391**

3.2.2.2. OPEX

For the OPEX costs, the general assumptions for all the pre-feasibility studies are described in ANNEX 4 – CAPEX AND OPEX (ITEMS DEFINITIONS).

Table 16. Operating costs

OPERATING COSTS	TOTAL
FIXED COSTS	**USD/year**
Personnel	$ 32,520
Laboratory	$ 2,100
Maintenance	$ 15,852
SUBTOTAL FIXED COSTS	**$ 50,472**
VARIABLE COSTS	**USD/year**
Biosolids transportation	$ 2 546(1)
Biosolids disposal	$0(2)
Chemical reagents/ Biogas treatment	$ 619(3)
Electrical power	$ 509(4)
SUBTOTAL VARIABLE COSTS	$3 674
TOTAL OPEX	**$54 146**

Notes:

1. MXN$ 136/ton was assumed for transportation costs, but this cost is unknown because the final use site and who would pay for it is unknown.
2. No disposal costs are assumed, the biosolid can be used to inoculate another anaerobic reactor or as a fertilizer.
3. Cost of the replacement of iron sponge for biogas treatment. No other chemical addition was considered. Nevertheless, this amount should be reviewed after the analysis of the neutralization and existing addition of coagulant and flocculant. Maybe saving costs due to a reduction regarding chemical addition can be considered.
4. This amount corresponds to the electricity consumption of the electromechanical equipment installed.

3.2.2.3. Revenues/savings

The project would have some saving costs due to production of energy for self-consumption and due to pollution fees avoided. The related calculations are shown in Table 17:

Table 17. Revenue and savings

ELECTRICITY		
Motogenerator	kW	115
Operation Hours	h/year	6 989
Electricty production	kWh/year	803 712
Electricity cost	$/Kw	**2.3**
Electricity savings at NORSON's slaughterhouse	**USD/year**	**$ 97 291**
HEAT		
Natural gas that could be replaced	m^3natural gas/year	105 035
Cost of natural gas	$\$/m^3$	**5.0**
Electricity savings at Norson's slaughterhouse	**USD/year**	**$ 27 663**
WASTEWATER POLLUTION FEES		
Wastewater flow	m^3/month	36 043
Fee	$\$ / m^3$	**1.72**
Wastewater pollution fees savings	**USD/year**	**$ 39 154**
TOTAL		**$ 164 109**

3.2.2.4. Payback period

The calculations of the payback period are shown in Table 18. These figures do not consider inflation rates or interests related to bank loans.

Table 18. Payback period calculation

		UASB AND CHP
CAPEX	$USD	$882 391
OPEX	$USD/year	$54 146
Incomes (savings)	$USD/year	$164 109
PAYBACK PERIOD	**years**	**8.0**

3.2.3. Collateral benefits

3.2.3.1. GHG Reduction

ASUMPTIONS:

- The GHG reduction from UASB at Norson slaughterhouse may come from the production of clean energy, in terms of electricity and heat.
- Electrical emission factor is 0.582 ton_{CO2}/MWh (CRE, 2017)
- Natural gas emission factor is 2.27 $kg_{CO2eqq}/m^3_{natural\ gas}$ (INECC, 2014).
- Methane density at normal conditions is 0.656 kg/m^3
- Calculations:

Table 19. GHG Reductions

GHG reduction due to clean energy (electricity)		
Emission Factor	0.582	ton_{CO2}/MWh
Electric generation	798 785	kWh/year
GEI reduction due to electricity production	465	ton_{CO2}/year
GHG reduction due to clean energy (heat)		
Emission Factor	2.27	kg_{CO2}/m^3 natural gas
Heat generation	105 035	m^3 natural gas/year
GEI reduction due to heat production	238	ton_{CO2}/year
TOTAL GHG emissions avoided	**703**	**ton_{CO2}/year**
Investment of anaerobic system	**882 391**	**$USD**
Cost per m^3 avoided GHG	**1 255**	**$USD/$ton_{CO2}$**

Year	CAPEX	OPEX	INCOMES	ANUAL EXPENSES	ACCUMULATED ANNUAL EXPENSES	ACCUMULATED REDUCTION OF GHG	COST PER M3 OF AVOIDED GHG
0	$882 391	$0	$0	$882 391	$882 391	0	-
1	$0	$54 146	$164 109	-$109 963	$772 428	703	$1,098.3
2	$0	$54 146	$164 109	-$109 963	$662 465	1 407	$471.0
3	$0	$54 146	$164 109	-$109 963	$552 502	2 110	$261.9
4	$0	$54 146	$164 109	-$109 963	$442 539	2 813	$157.3
5	$0	$54 146	$164 109	-$109 963	$332 576	3 517	$94.6
6	$0	$54 146	$164 109	-$109 963	$222 612	4 220	$52.8
7	$0	$54 146	$164 109	-$109 963	$112 649	4 923	$22.9
8	$0	$54 146	$164 109	-$109 963	$2 686	5 627	$0.5
9	$0	$54 146	$164 109	-$109 963	-$107 277	6 330	-$16.9
10	$0	$54 146	$164 109	-$109 963	-$217 240	7 033	-$30.9

The cost per m3 of avoided GHG depends on the stage of the project. The first year, it costs up to USD 1 098/ton_{CO2}, but after 8 years the cost of the project have been recovered and so, there are not costs related to avoiding GHG emissions, on the contrary, there are revenues.

3.2.3.2. Nitrogen recycle

ASUMPTIONS:

- Nitrogen recycle only comes from the granular sludge purged from the UASB, not from the anaerobic effluent; this last one would be discharged into sewerage.

Table 20. Calculations of N recycle

Calculations of N recycle		
Feedstock quantity	432 519	m3/year
COD concentration	2.15	kg/m3
COD removed in UASB	70%	
Biomass yield	0.12	$kg_{TSS}/kg_{CODremoved}$
Biomass production	78	ton_{TSS}/year
VSS/TSS ratio	0.60	g_{VSS}/g_{TSS}
Concentration of N in granular sludge	80	kg_{N}/ton_{VSS}
Nitrogen equivalence per year	**3.8**	**ton_{N}/year**
N content in urea	0.47	kgN/kg_urea
Urea molecule equivalent	**0.01**	**tons/year**

% purity fertilizer		44%	
Urea fertilizer equivalent		**0.02**	**tons/year**
Market price as fertilizer		7000	MX$/ton
Price equivalentce	**$**	**7**	**USD$/year**

3.2.4. Conclusions

3.2.4.1. Key figures

For the anaerobic and biogas system at NORSON's slaughterhouse:

- The investment cost is less than USD 882 391
- The payback period is less than 8 years
- The electricity production is 115 kW.
- The GHG reduction is 703 ton/year.
- The nitrogen recycle as nutrient is 4 ton$_N$/year.

The economic feasibility of this project could be better than the figures shown above, since the monetary saving due to less chemical dosage and extra incomes from granular sludge selling can be accounted in a further detailed evaluation.

3.2.4.2. SWOT analysis

Table 21. SWOT Analysis

STRENGTHS **What are the main reasons for choosing this site?**	**WEAKNESSES** **What are the main reasons for not choosing this?**
- Easy to use biogas on site: high energy demand of all kinds (electricity, natural gas, fuel for vehicles, etc.)	- No existing agricultural areas nearby for treated wastewater and digestate reuse. - There are two options for discharging treated wastewater: 1) Municipal sewerage: low quality limits to discharge ww are required; however, current fees to discharge into sewerage above limits is very low, so no important savings by cleaning the water to meet more strict limits 2) Selling ww to the Municipality and industries nearby: high quality standards must be achieved. - The UASB effluent (rich of nutrients) cannot be used for agricultural irrigation (35-40km far) and it must be led to the sewage system. - Existing municipal WWTP has anaerobic digesters and co-generators. Low climate and environmental impacts can be achieved by moving wastewater from one biodigester to another.
OPPORTUNITIES **- How can strengths be used and weaknesses be overcome?**	**THREATS** **- What are the main risks related to a project at this site?**
- Potential reduction of chemical costs. - Potential selling of granular sludge from UASB. - Potential urban public reuse of treated water. - It might be possible to establish a crop or tree production nearby that can absorb the nutrients and lower the amount of waste water led to municipal sewages which can lead to savings on fees for WW	- Reduction of the area available for the strategic growth of NORSON´s production. - Collateral benefits (reuse of nutrients and reduction of GHG) are low.

3.2.4.3. Lessons learned

- **THERE IS NO PROPER INCENTIVES FOR THE INDUSTRIES TO TREAT WASTEWATER**. The wastewater pollutions fee ($ 1.7/m3) for not complying the norm is very low compared to the sewerage discharge fee ($22.9/m3).
- **INDUSTRIAL DISCHARGES ARE CAUSING OPERATIONAL PROBLEMS AT MUNICIPAL WWTP**. Industries are discharging raw wastewater into the sewerage, which has caused peak concentrations higher than expected in the municipal WWTP and unusual high sulphur concentrations in the biogas of the WWTP. The latter is a current problem in the Hermosillo WWTP.
- **VALORIZATION OF SLUDGE** is important in terms of environment, economic and technical benefits. Additionally, the potential market for anaerobic granular could significantly improve if industries at Hermosillo treats their own wastewater.
- **THE ECONOMIC INCENTIVES ARE LACKING; THE FEASIBILITY OF CLEAN ENERGY PROJECTS DEPENDS ON THE PUBLIC IMAGE OF THE COMPANIES.** For industries with high revenues like Norson, environmental projects are not expensive and may represent competitive difference mainly for international trades. Although an anaerobic plant itself can be a business after 8 years under current conditions, this payback period may be long for the industries in terms of opportunity cost.
- **MUNICIPAL IRRIGATION OF TREATED WASTEWATER CAN BE PROMOTED.** In this manner, the industries could avoid fees due to sewerage discharging.

3.2.4.4. Following steps

- Red stream characterization of the slaughterhouse, preferable under future conditions, in which Norson is supposed to optimize water use and to discharge it, they will discharge less wastewater per pig slaughtered and a more concentrated wastewater.
- The chemical agents used in the slaughterhouse (mainly cleaning) should be reviewed in order to verify the presence and concentration of inhibitors.
- The performance of the existing facility should be reviewed (grease tramps, equalization tank, neutralization step, screens, DAF, etc).
- Jar tests should be carried out in order to reduce chemical dosage costs at the DAF system, this could optimize biogas production. These costs should be included in a further economic study.
- Equalization tank volume and final use of the biogas should be reviewed in order to propose the optimum volume for the biogas holder.
- Footprint of the UASB and biogas facility should be reviewed. In case of lack of space, biogas burner can be closed in order to reduce the security free area, but it is more expensive.
- Heat use site should be reviewed in order to calculate heat losses and pumping of hot water costs.
- Market for the granular sludge use should be explored.

3.3. Pre-feasibility study 3. Co-digestion of industrial residues at WWTP

3.3.1. Technical pre-evaluation

The industrial residues mixture proposed for the co-digestion project are the solid residues from Norson and Pegson, as well as the DAF sludge from IlLIS, all them coming from the Industrial Park in Hermosillo. In addition, this mixture also includes the residues from grease tramps that "Agua de Hermosillo" is currently receiving at the industrial WWTP.

The sludge from septic tanks and portable toilets, residues that are being handled by "Agua de Hermosillo" at the industrial WWTP and poorly treated, were excluded from this proposal. Sludge from septic tanks has low potential methane production, and portable toilets tend to use biocides and other toxic compounds for the biological treatment.

The mass balance of the industrial solid residues available -according to the site visits-in Hermosillo are shown in the Table 22.

Table 22. Mass balance of solids residues for codigestion

	Residue production	Dry matter	Methane potential[2]	Production of methane	H_2S conc. [2]
	ton/year	**%TS**	**m^3CH_4/ton**	**m^3CH_4/year**	**%**
Fats (screen)	765	11.0	54.0	41 310	< 0.1
Semi-dry DAF sludge[1]	882	19.3	57.2	50 458	< 0.1
Stomach/ Intestine content	576	30.0	119.0	68 544	< 0.05%
Flotation fat	218	11.0	54.0	11 755	< 0.1
Residue blood	288	1.0	24.0	6 912	< 0.1
Manure (corrals)	480	10.0	20.8	9 984	0.2
DAF sludge	456	4.0	29.1	13 248	< 0.1
Grease tramps	4 565	11.0	54.0	270 864	< 0.1
FEEDSTOCK FOR CO-DIGESTION	**8 229**	**12.4**	**54.5**	**448 697**	**< 0.1**

Notes:

1. By using drying beds, Norson significantly reduce the volume of DAF sludge that has to be disposed to TECMED, which is convenient in terms of transportation and disposal costs, but it is not favorable for the codigestion project, because the sludge would be very dry and semi-digested. In this calculation it was assumed that the sludge from DAF (4% TS aprox) is dewatered at the drying beds in Norson until a maximum concentration of 20% of TS, during no more than one week. The latter may represent an extra cost for Norson regarding transportation, but it could be compensated if disposal costs are reduced.
2. Values reported in SENER, DEA, IBTech, Clúster de biocombustibles gasesos and II-UNAM (2018) Feedstock database for biogas in Mexico.

The proposal is to transport these residues to the municipal Hermosillo WWTP and install a co-digestion system. Co-digestion refers to the simultaneous treatment of certain quantities of organic material from different sources in an anaerobic digester. In this case the organic material would be the industrial solid residues and the sludge from the WWTP; the digesters would be the existing ones at Hermosillo WWTP. That may require technical adaptation, consisting mainly in a reception and conditioning system of the external residues, as seen in Figure 44.

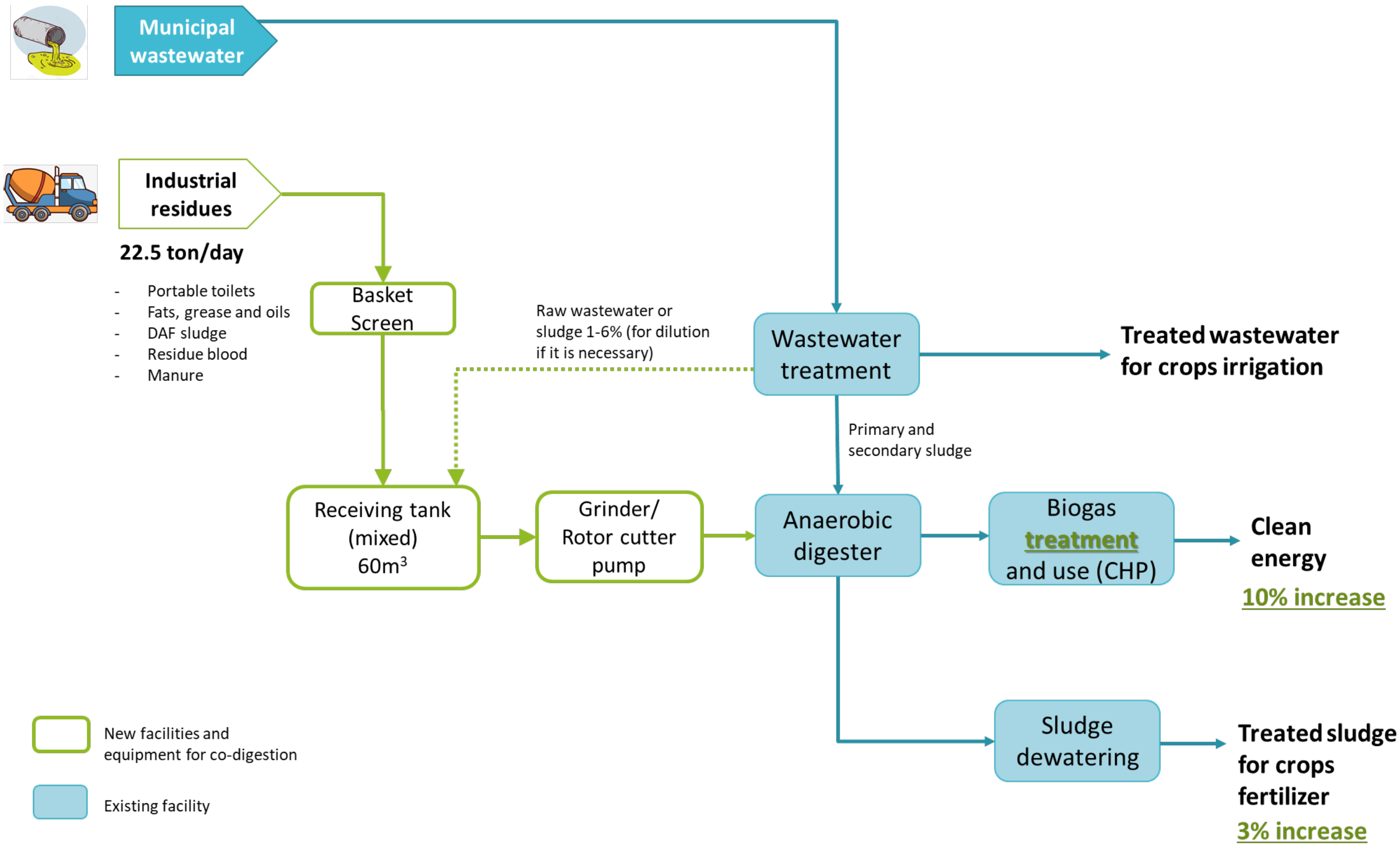


Figure 44. Co-digestion proposed for Hermosillo WWTP

Although in Mexico has not been practiced yet, in Europe and USA is a known way of treatment. Some examples of biogas plants in which codigestion is practiced in Denmark are shown in "Biogas plants in Denmark and Mexico" (DEA, Ea Energy Analyses and IBTech, 2019).

The objectives of co-digestion are (EnRes, 2017):

- Use the capacity of an existing digester, in many cases the digesters have significant unused potential.
- Optimize the technical conditions of the process (improve the organic content of the substrate, the C: N ratio, the pH adjustment, etc.).
- Respond to a demand for local use of biogas.

In this case, the co-digestion project may increase 4.5% the solids load to the digester biogas (and so the sludge disposal). About 80% of the industrial solids may be grease and fogs, nevertheless, when they are mixed with sludge from WWTP, the mixture influent to the anaerobic digester may have only 3% approximately of FOGs, which is below the maximum recommended values. Due to the high methane potential of FOGs, the feed of these industrial fatty residues may increase by 10% the biogas production and, consequently, the potential generation of energy.

3.3.2. Receiving and conditioning step of industrial residues

The industries should dispose their residues (feedstocks) by truck or pipe as continuously as possible, preferable in a daily basis (27 ton/day in total aprox), without other inorganic materials and in pieces no more than 10cm long.

Figure 45. Example of a 600m^3 receiving tank underground at Hashøj biogas plant in Denmark (110 000tons/year). Trucks deliver under a covered in order to avoid smell (left) and pipes deliver feedstock outside into closed pipelines. (Courtesy: Bodil Harder/DEA)

At the reception, for security reasons, it is recommendable to install a coarse basket screen. The residues may enter to a mixed tank 60m^3 of 2 days retention time. At the bottom of the tank, the feedstock is pumped through a “grinder” or “rotor cutter”. This equipment has a series of interleaving cutters and spacers that gives a positive displacement solid grinding. Each equipment must be supplied with a PLC in order to protect the machine against damage from rogue materials and overloads.

Grinding feedstock is necessary before anaerobic digestion in order to get a homogenous sludge that can easily mix with the sludge coming from WWTP.

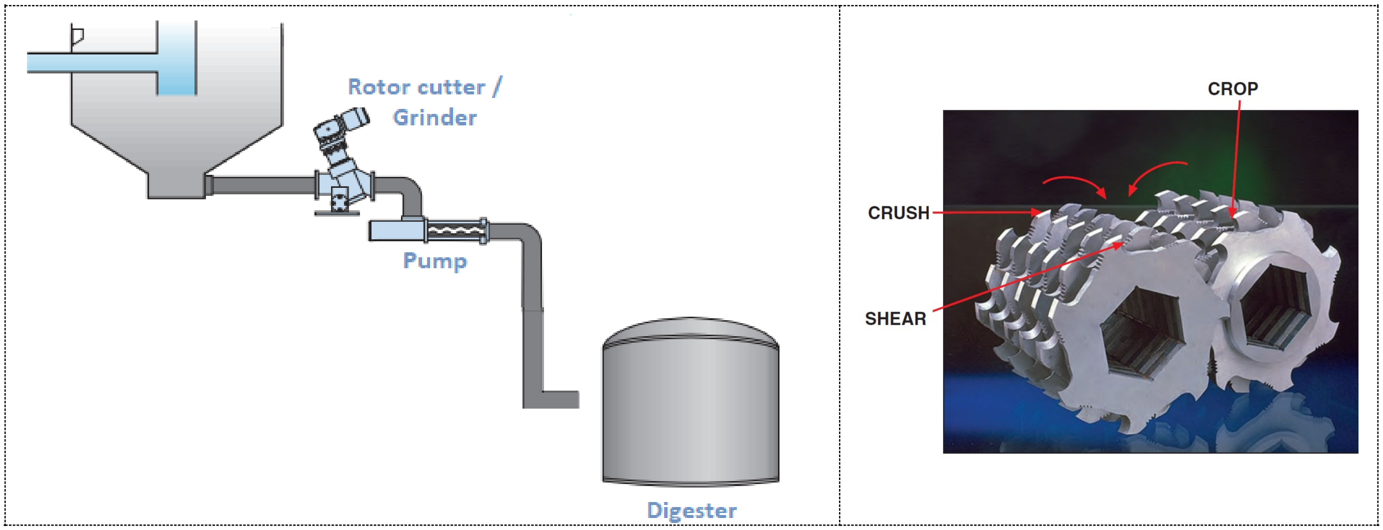


Figure 46. Rotor cutter/ Grinder upstream anaerobic digester a) Location, b) Zoom to cutter stacks (http://www.mono-pumps.com/en-uk/webfm_send/2928)

3.3.3. Anaerobic digester at WWTP

Based on the information gathered during the visit to the WWTP, the WWTP performance was calculated for the design scenario in which both primary and secondary sludge are treated at the anaerobic digesters. As a reminder, currently the primary sludge is not entering the anaerobic digester due to unexpected high concentration of sands in raw wastewater that are settling within primary sludge.

The comparison of the designed scenario for the WWTP and the one existing in case of co-digestion project are shown in Table 23. In order to maintain at least 20 days of sludge retention time at the digesters, the sludge entering to the anaerobic digesters should be concentrated slightly more, from 6.0% to 6.1%. It is important to confirm if the mixing system at the anaerobic digesters can still handle solids up to 6.2% concentration, from which 3% (out of 100% dry weight) are fats and oils.

In general, it seems that the co-digestion project would not affect or demand a change at the existing facilities of the WWTP.

Table 23. Calculation anaerobic digesters capacity under current design and proposed co-digestion scenario.

DESIGN SCENARIO OF THE WWTP		
PRIMARY AND SECONDARY SLUDGE		
Solids load	74 997	kgTSS/d
Sludge concentration	6.0	%
Sludge flow entering to the digester	1 250	m^3/d
Volume of anaerobic digesters	24 960	m^3
Sludge residence time	**20.0**	**d**
SCENARIO OF THE WWTP WITH CODIGESTION		
PRIMARY AND SECONDARY SLUDGE		
Solids load	74 997	kgTSS/d
Sludge concentration	6.1	%
Sludge flow	1 225	m^3/d
FEEDSTOCKS		
Yearly production	8 229	ton/year
Solids concentration	12.4	%
Solids load	2 802	kgTSS/d
Density	0.91	ton/m^3
Solids flow	24.8	m^3/d
TOTAL (MIXED FLOWS ENTERING TO THE DIGESTER)		
Solids load	77 799	kgTSS/d
Sludge concentration	6.2	%
Sludge flow entering to the digester	1 250	m^3/d
Volume of anaerobic digesters	24 960	m^3
Sludge residence time	**20.0**	**d**

3.3.4. Sludge handling at WWTP

When more solids enter the anaerobic digesters, more solids would be present at the outlet. As noticed in Table 24., the amount of solids to be disposed under codigestion scenario are 7.3 tons per day more than those to be disposed under design scenario of the WWTP, which would represent 4% additional sludge to be transported and disposed. For sure, it is highly recommendable from the economical, technical and environmental point of views, to avoid the disposal of solids at TECMED landfill and instead, using it as fertilizer at agricultural areas.

ASSUMPTIONS:

- VSS destruction in the anaerobic digester= 46%
- Solids concentration after dewatering= 26%
- VSS/TSS fraction:
    - For WWTP's sludge= 75%
    - For industrial residues with high content of FOGs= 90%

Table 24. Sludge production under current design and proposed co-digestion scenario.

		DESIGN SCENARIO OF THE WWTP	ADDITIONAL FEEDSTOCKS	SCENARIO OF THE WWTP WITH CODIGESTION
SLUDGE				
Solids load	kgTSS/d	74 997	2 802	77 799
Solids flow	m^3/d	1 224	25	1,250
VSS destroyed at the digester	%/100	**0.46**	**0.46**	0.46
%VSS assumed	%/100	0.75	0.90	0.76
SSV destroyed	kgVSS/d	25 874	1 160	27 034
Solids load at the outlet of digester	kgTSS/d	49 123	1 642	50 765
Concentration of digested sludge	%TSS	4.0	6.6	4.1
Concentration of sludge dewatered	%TSS	26.0	26.0	26.0
Volume of dewatered sludge	m^3/d	188.9	6.3	182.4
Density	ton/m^3	1.1	1.1	1.1
Tons of dewatered sludge	**ton/d**	**207.8**	**6.9**	214.8
Contribution to the total sludge produced		**96.6%**	**3.2%**	**100.0%**

3.3.5. Biogas and electricity production at WWTP

The motogenerators at Hermosillo WWTP were designed to operate 77% of the time, this means, 6 723 hours per year. The co-digestion of the industrial feedstocks at Hermosillo WWTP would allow to operate the motogenerators an additional amount of 660 hours per year; this means an increase of 10% in terms of operation time compared to the WWTP design conditions. The calculations regarding biogas and electricity production under design conditions and under the proposed co-digestion scenario are shown in Table 25.

ASSUMPTIONS:

- Methane generation factor= 0.35 m^3CH_4/kg_{COD} removed

- Energy factor= 10 kWh/ m^3CH_4
- Electrical efficiency of CHP= 36.6% (according to Guascor equipment information)
- No heat use considered, the digesters of Hermosillo WWTP are not heated.

Table 25. Biogas production under current design and proposed co-digestion scenario.

Biogas production under current design and proposed co-digestion scenario		
Number of CHP		3
CHP model		**SFGLD 480 GUASCOR at 1800rpm**
Nominal electricity capacity of each CHP	kW	**874**
Total capacity installed	kW	**2 622**
DESIGN SCENARIO OF THE WWTP		
SSV destroyed	kgVSS/d	25 874
Biogas production factor	m^3/kgSSVdest	0.75
Biogas production	m^3/d	19 405
Methane content	%/100	0.68
Year mehane production	m^3CH_4/year	4 816 421
Electricity production	kWh/year	17 628 101
Hours of operation per year	hrs/year	6 723
Percentage of the time that CHP is in operation		**77%**
ADDITIOINAL FEEDSTOCK		
Additional methane production per year(1)	m^3CH_4/year	448 697
Additional electricity production	kWh/year	1 642 233
Additional operation hours per year	hrs/year	626
SCENARIO OF THE WWTP WITH CODIGESTION		
Methane production per year	m^3CH_4/year	5 25 118
Electricity production	kWh/year	19 270 333
Operation hours per year	hrs/year	7 349
Percentage of the time that CHP is in operation		**84%**

Notes:

1. See Table 21- Mass balance

As described in Chapter 2.4., currently the CHPs are not operating due to the small amount of biogas that is being produced (the primary sludge is not entering to the digester) and due to the bad quality of biogas (concentration of up 5 000ppm H_2S). In order to move from current low gas production to the design values, a better system for sands removal should be installed. This would allow to enter primary sludge into the anaerobic digesters and this is expected to increase biogas production up to design values.

As shown in Table 21 Mass balance., the biogas generated from industrial feedstocks would not increase the current concentration of H_2S in the biogas.

Nevertheless, with or without co-digestion, it is indispensable to treat properly the biogas in order to reduce H_2S concentrations and use biogas in CHPs. As a parallel project, it would be highly recommendable for the operator of the WWTP (TIAR) to consider a biological desulphurization equipment (such as BiogasClean®) instead of the chemical addition of ferric chloride (as used). Although the biological desulphurization has higher investment costs, it can be the best option in this case due to the following reasons:

1. It would be more efficient, the H_2S content in biogas can easily decrease from 5 000ppm to less than 500ppm as recommended by the supplier of the CHP.
2. The operation would be cheaper due to no consumption of chemicals for desulphurization of biogas, which is a great advantage considering that TIAR would operate the WWTP for 15 more years.
3. TIAR (FYPASA) has already an experience with the BiogasClean® at León WWTP where EnRes/GIZ (German Cooperation) is currently starting-up this equipment. There could be an exchange of learnings and experiences.

Figure 47. Biogas Clean installed in León WWTP (Courtesy: ECOSYS III/ FYPASA)

3.3.6. Final remarks

ADDITIONAL PREMIXER

It is recommendable to carry out a characterization and a further analysis of the feedstocks. In case that test shows that the rotor cutter proposed is not enough to mix properly the feedstocks, an additional equipment like

PreMix/ Vogelsang could be used. The PreMix: a) separates out heavy material while still upstream of the integrated pump unit, b) mixes solid and paste-like input materials with a liquid suspension into a homogeneous suspension, and c) coarse particles and fibrous matter are shredded.

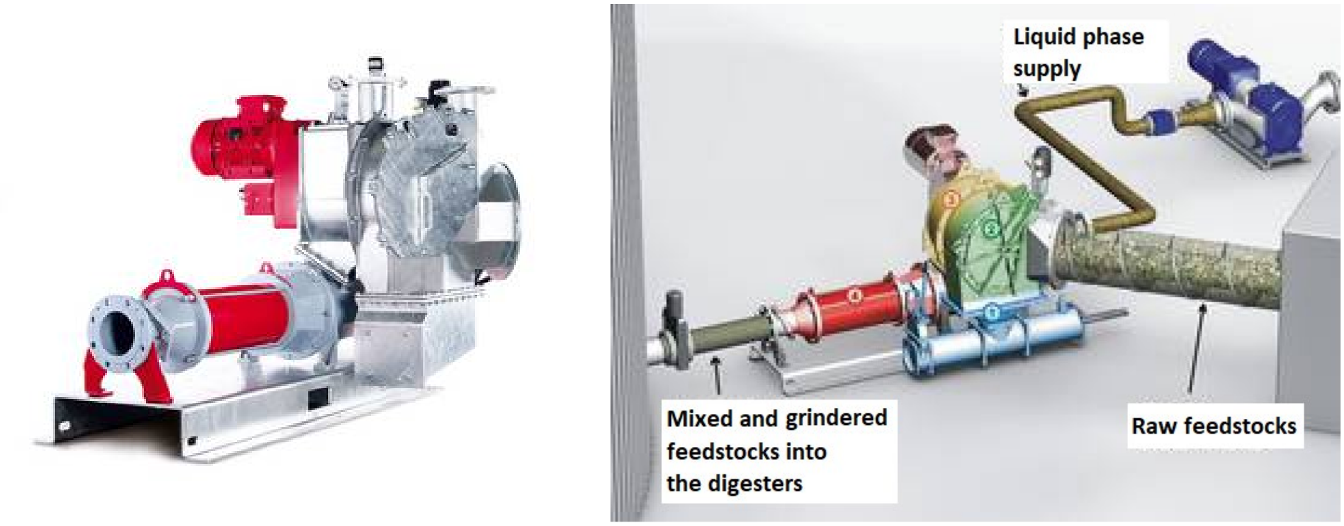


Figure 48. Picture of PreMix, Vogelsang
(https://www2.vogelsang.info/dk/products/solid-matter-feeder/premix/overview/)

PASTEURIZATION/ HIGIENIZATION STEP

In Denmark, the feedstocks use to enter to rather a hygienization or pasteurization step, or even a thermophilic digester upstream the mesophilic digesters. The objective of this step is to kill pathogens and promote hydrolysis. Nevertheless, it is worthy to mention that if this step is necessary, the heat from CHP (currently dismissed) could be used. The heat that would be produced in CHPs under a co-digestion scenario is approximately 23 780 Gcal/year, which is enough to heat from 30°C to 70°C the amount of 481 554 m^3 per year. As shown in Table 24., the yearly flow inlet to the anaerobic digesters is 1250 x 365= 456 250 m3 per year. So theoretically, the heat produced in CHP under a co-digestion scenario would be enough for a hygienization or pasteurization step. The economic analysis of a hygienization or pasteurization is not included in this pre-feasibility study, but it should be worthy in case of existence of a real market for a better quality of sludge (Class A or B) in order to use it as fertilizer.

Figure 49. Example of three pasteurized tanks (back) and heat exchangers (front) at Hashøj biogas plant in Denmark (110 000tons/year). (Courtesy: Bodil Harder/DEA)

3.3.7. Economical pre-evaluation

3.3.7.1. Business model

The proposed business model is the re-negotiation of the contract between "Agua de Hermosillo" (WWTP owner) and TIAR (WWTP operator) in order to include investment, reception, installation, operation and conditioning of the feedstock system for co-digestion in the scope of the contract. A "disposal fee" of $100/ton would be paid by the industries to the Hermosillo WWTP in order to get rid of their residues there. Feedstocks will be required to meet certain qualities in order to be accepted, such as: no inorganic materials, no pieces longer than 10cm, no residues of more than one week of storage, full characterization twice per year, and others.

The stakeholders would have the following benefits:

- INDUSTRIES:
  - **Transportation saving costs.** The industries would transport their residues to Hermosillo WWTP (20km far) instead of TECMED landfill (45km). In this pre-feasibility study, a reduction in transport costs of approximately 20% was assumed (from $136 to $110 per ton). Transportation costs to the WWTP should be confirmed in a further detailed analysis.
  - **Disposal saving costs**. The industries would pay an amount of $100 per ton to dispose their residues into the WWTP, instead of paying $250 per ton to dispose them into TECMED landfill. The objectives of this tariff are:

a) Encourage the disposal of industrial residues to the WWTP.

b) To compensate additional costs that the industries may have due to the feedstocks quality requested in order to be disposed into the WWTP.

c) To dispose of residues (like FOGs) that are currently being discharged into the industrial WWTP of "Aguas de Hermosillo" without a proper treatment for free.

- HERMOSILLO WWTP:
  - **Revenues from additional electricity production in the existing CHPs and disposal fees paid by the industries.** After certain years this will pay off the investment and will get additional incomes.
- COMMUNITY:
  - The future revenues at the WWTP would decrease operational costs and could reduce the water tariff for the people living in Hermosillo.
  - The co-digestion project could have collateral benefits (clean energy and recycled nutrients) that will promote sustainable development and environmental objectives in Hermosillo.

3.3.7.2. CAPEX

ASSUMPTIONS:

- The prices shown are preliminary estimations that must be confirmed in a furthermore detailed evaluation.
- Electricity cost: MX**$2.3/kWh** (intermediate rate at Hermosillo for medium tension, industrial purposes, price according to Norson).
- **No heat recovery** considered
- Exchange rate: MX$19/USD
- Prices given does not include taxes (VAT 16%)

The cost estimation includes only the system required for the receiving and conditioning system for co-digestion. There are no other investment costs for anaerobic digestion, as well as sludge and biogas handling. The system proposed was as simple as possible; any structure with lid/cover at the receiving tank, bad odors treatment, premixer, hygienization or pasteurization step were considered.

a) Electromechanical equipment estimation

The main electromechanical equipment is listed in Table 26.

Table 26. Estimation of costs of electromechanical equipment

PRETREATMENT	COST (USD$)

	- Coarse screen, stainless steel - Platter for solids, stainless steel - Security perimeter handrail, carbon steel Ced. 30 1-1/2" D	$13 924
RECEIVING MIXED TANK		
	- Closed tank, glazed steel, 60m3 capacity with 80x80cm manhole - Two mixers of 5HP, 10in impeller, shaft and impeller of SS316L - Level meter. - Inspection perimeter handrail.	$138 481
ROTOR CUTTER/ GRINDER AND MONO-PUMP		
	- Three lobe pump 5HP (2+1 stand-by), Vogelsang brand, 1.0kg/cm2 pressure discharge, 3in discharge diameter - Three rotor cutter / solids grinder (2+1 stand-by), 5HP, Vogelsang brand, 1.0kg/cm2 pressure discharge, 3in discharge diameter. It includes control panel. - Valves, connection accessories and pipes	$151 277
DILUTION PUMP		
	- Submersible pump fro 12L/s, 5HP, pressure discharge 1.0 kg/cm2, 3in discharge pipe. - Valves and connection accessories	$10 032
TOTAL		**$313 714**

b) Total investment costs

The description and scope of each item of the table below, related to the CAPEX costs, is described in ANNEX 4 – CAPEX AND OPEX (ITEMS DEFINITIONS).

Table 27. Summary of total investment costs

DESCRIPTION	USD$
Electromechanical equipment	$ 313 714
Civil works and structures	$ 75 605
Electrical installation	$ 52 390
Piping and mechanical installation	$ 66 194
External works	$ 22 274
Engineering project	$ 38 000
Start-up	$ 20 000
TOTAL	**$588,176**

3.3.7.3. OPEX

For the OPEX costs there are two scenarios:
SCENARIO A- CURRENT SITUATION. It is assumed that the dewatered sludge is transported and disposed to TECMED land (55 kms far).

SCENARIO B- USE OF SLUGE AS FERTILIZER. It is assumed that the sludge is sent to agricultural areas nearby (50% saving costs regarding transportation compare to the first scenario) also, the sludge is supposed to be delivered for free to the farmers (no disposal cost, neither revenues).

Table 28. Operating costs

OPEX	A. CURRENT SITUATION	B. USE OF SLUDGE AS FERTILIZER
FIXED COSTS	USD/year	USD/year
Personnel(1)	$ 21 020	$ 21 020
Laboratory(2)	$ 0	$ 0
Maintenance(3)	$ 20 321	$ 20 321
SUBTOTAL FIXED COSTS	**$ 41 342**	**$ 41 342**
VARIABLE COSTS		
Biosolids transportation(4)	$ 20 988	$ 10 494
Biosolids disposal(5)	$ 34 981	$ 0
Chemical agents(6)	$ 9 614	$ 9 614
Electrical power(7)	$ 16 380	$ 16 380
SUBTOTAL VARIABLE COSTS	**$ 81 962**	**$ 36 488**
TOTAL OPEX	**$ 123 304**	**$ 77 829**

Notes:

1. It was assumed an extra cost for technical and administrative personnel for the receiving and conditioning step of the co-digestion.
2. No laboratory analysis of feedstocks was included.
3. The maintenance costs consider just the electromechanical equipment included in the receiving and conditioning step.
4. MX$ 150/ton was assumed for transportation costs to TECMED landfill (55km far), this price is low because the WWTP owns their own trucks, but it should be verify in a further detailed economic analysis. The half of this cost was assumed for transportation costs if sludge is disposed into agricultural areas nearby.
5. MX$ 250/ton was assumed for disposal into TECMED landfill. This is a fixed price.
6. Additional flocculant for dewatering. Dosage= 4kg_{flocc}/ton_{solids}. Price of flocculant= USD$8.42/kg
7. This amount corresponds to the electricity consumption of the electromechanical equipment included in the receiving and conditioning step.

3.3.7.4. Revenues/savings

a) Transportation and disposal saving costs for industries

NORSON

Norson could have almost no savings. In order to dispose of the sludge in the Hermosillo WWTP, it should be moistier (more volume), which means an increase in transport costs. The extra costs for transportation would be compensated with a reduction of disposal costs.

Table 28. Transportation and disposal saving costs for Norson

EXPENSES UNDER CURRENT SITUATION				
TOTAL SOLIDS RESIDUES	**ton/year**	**1 017**		
Transportation to TECMED landfill (45km)	$/ton	136	$USD/year	7 280
Disposal to TECMED landfill	$/ton	250	$USD /year	13 382
Total expenses			**$USD /year**	**20 661**
EXPENSES IF CO-DIGESTION PROJECT				
TOTAL SOLIDS RESIDUES	**ton/year**	**1 647**		
Transportation to WWTP (20km)-20% Savings	$/ton	110	$USD /year	9 535
Disposal to Hermosillo WWTP	$/ton	100	$USD /year	8 668
Total expenses			**$USD /year**	**18 204**
SOLIDS HANDLING SAVINGS IN CASE OF CO-DIGESTION PROJECT			**$USD/year**	**2 457**

PEGSON

Pegson could save USD$ 22 685 per year regarding solids handling, which represent a significant reduction of 46%, compared to the expenses of transportation and disposal under current situation.

Table 29 Transportation and disposal saving costs for Pegson

GENERATION OF SOLIDS RESIDUES	ton/year	1 562		
EXPENSES UNDER CURRENT SITUATION				
Transportation to TECMED landfill (45km)	$/ton	**136**	USD$/year	**11 178**
Disposal to TECMED landfill	$/ton	**250**	USD$/year	**20 548**
Total expenses			USD$/year	**31 727**
EXPENSES UNDER RECOMMENDED SITUATION (CO-DIGESTION)				
Transportation to WWTP (20km) - 20% savings aprox	$/ton	**110**	USD$/year	**9 041**
Disposal to Hermosillo WWTP	$/ton	**100**	USD$/year	**8 219**
Total expenses			USD$/year	**17 261**
SOLIDS HANDLING SAVINGS IN CASE OF CO-DIGESTION PROJECT			**USD$/year**	**14 466**

OTHER INDUSTRIES

ILIS and other industries that generate liquid residues (mainly FOGs) that are not discharged into the sewerage, pays transport and disposal of their liquid residues to a company that collects and disposes them probably to the industrial WWTP in Hermosillo. Each industry should carry out a further detailed evaluation regarding the convenience of taking their residues to Hermosillo WWTP.

a) Disposal fees paid by the industries to Hermosillo WWTP

Table 30 shows an estimation of the disposal fees, which represents revenues for Hermosillo WWTP. **The payment assumed by the industries to the WWTP is $100 Mexican pesos per ton.**

Table 30 Revenues for Hermosillo WWTP due to disposal fees

Industries	Amount of solid residues	Industries payment to the WWTP
	tons/year	**$USD/year**
NORSON	1 647	$8 668
PEGSON	1 562	$8 219
ILIS	456	$2 400
FOGs	4 565	$24 024
ANNUAL INCOMES	8 229	**$43 312**

a) Electricity savings

The project could have savings due to the production of self-consumption energy in the WWTP. The related calculations are shown in Table 31:

Table 31. Electricity savings

ELECTRICITY		
Additional electricty production in the WWTP	kWh/year	1 642 233
Electricity cost	$/kW	2.3
Electricity savings at WWTP	**$USD/year**	**$ 198 797**

1.1.1.1. Payback period

The calculations of the payback period are shown in Table 32. These figures do not consider inflation rates or interests related to bank loans.

The payback period of the co-digestion project is attractive; the time strongly depends on the valorization of the sludge. If the WWTP sludge continues to be dumped into TECMED landfill, the payback period of the project would be around 4.8 years. If the WWTP sludge is transported to agricultural areas nearby and disposed for free there, the payback period of the project would be around 3.4 years. It is recommendable to pursue an agreement with the farmers in order to use the sludge as fertilizer.

Table 32. Electricity savings

		A. CURRENT SITUATION	B. USE OF SLUDGE AS FERTILIZER
CAPEX	$USD	$ 588 176	$ 588 176
OPEX	$USD/year	$ 120 712	$ 77 343

Incomes (savings)$^{(i)}$	$USD/year	$ 242 108	$ 242 108
PAYBACK PERIOD	**years**	**4.8**	**3.6**

Notes:

1. The incomes considered were the sum of electricity savings (USD$ 198 797 per year) and the disposal fees (USD$ 43 312 per year).

3.3.8. Collateral benefits

3.3.8.1. GHG Reduction

ASUMPTIONS:

- The GHG reduction in the co-generation project may come from:
    - Additional clean energy (electricity) production.
    - Methane emissions avoided at TECMED landfill. The aerobic degradation of organic matter was assumed to be 30%.
    - Methane emissions avoided due to shorter transport distances
- Electrical emission factor is 0.582 ton_{CO2}/MWh (CRE, 2017)
- Emissions methane equivalence is 28 kg_{CO2eqq}/kg_{CH4} (SEMARNAT, 2016).
- Methane density at normal conditions is 0.656 kg/m^3
- All the residues are transported 20km instead of 45km, by trucks of 7 m^3 capacity.
- The trucks run 2.5 km per liter of diesel (Caminos y puentes, 2004).
- Emission factor for diesel is 2.6 kgCO2/L diesel (INECC, 2014)
- Calculations:

Table 32. GHG Reductions

GHG reduction due to clean energy		
Emission Factor	0.582	ton_{CO2}/MWh
Electric generation	1 642 233	kWh/year
GEI reduction	956	ton_{CO2}/year
GHG reduction due to methane emissions avoided at landfill		
Anaerobic degradation of residues at landfill	70%	
Methane generation	314 088	m^3CH_4/year
Methane density	0.656	kg/m^3
Emissions methane equivalence	28	kg_{CO2eqq}/kg_{CH4}
GEI emissions avoided	5 769	tonCO2/year
GHG reduction due to transportation 20km instead of 45km		
Fuel consumed by a 7m3 truck	2.5	km/L diesel
CURRENT SITUATION		
Sludge quantity	7 599	ton/year
Number of trucks 7m3	1 086	trucks/year

Distance to landfill	45	km
Diesel consumed	19 541	L/year
CODIGESTION SCENARIO		
Sludge quantity	8 229	ton/year
Number of trucks 7m3	1 176	trucks/year
Distance to landfill	20	km
Diesel consumed	9 405	L/year
GEI reduction		
Diesel NOT consumed in case of codigestion project	10 136	L/year
Emission factor for diesel	2.6	kg$_{CO2}$/L$_{diesel}$
GEI emissions avoided	26	ton$_{CO2}$/year
TOTAL GHG emissions avoided	**6 751**	**ton$_{CO2}$/year**
Investment cost	**588 176**	**USD**
Cost per ton avoided GHG	87	**USD/ton $_{CO2}$**

Year	CAPEX	OPEX	INCOMES	ANUAL EXPENSES	ACCUMULATED ANNUAL EXPENSES	ACCUMULATED REDUCTION OF GHG	COST PER M3 OF AVOIDED GHG
0	$588,176	$0	$0	$588,176	$588,176	0	-
1	$0	$120,712	$242,108	-$121,396	$466,780	6,751	$69.1
2	$0	$120,712	$242,108	-$121,396	$345,384	13,503	$25.6
3	$0	$120,712	$242,108	-$121,396	$223,988	20,254	$11.1
4	$0	$120,712	$242,108	-$121,396	$102,591	27,005	$3.8
5	$0	$120,712	$242,108	-$121,396	-$18,805	33,756	-$0.6
6	$0	$120,712	$242,108	-$121,396	-$140,201	40,508	-$3.5
7	$0	$120,712	$242,108	-$121,396	-$261,597	47,259	-$5.5
8	$0	$120,712	$242,108	-$121,396	-$382,994	54,010	-$7.1
9	$0	$120,712	$242,108	-$121,396	-$504,390	60,761	-$8.3
10	$0	$120,712	$242,108	-$121,396	-$625,786	67,513	-$9.3

The cost per m3 of avoided GHG depends on the stage of the project. The first year, it costs up to USD 69.1/ton$_{CO2}$, but after 4.8 years the cost of the project have been recovered and so, there are not costs related to avoiding GHG emissions, on the contrary, there are revenues.

3.3.8.2. Nitrogen recycle

ASUMPTIONS:

1. Nitrogen content in industrial residues would end up in the sludge or in the treated wastewater, both sub-products are used in agricultural lands. Nitrogen removal due to nitrification and denitrification process in the activated sludge system was neglected. The figures of nitrogen concentration in the industrial residues were the values reported by SENER, DEA, IBTech, Clúster de biocombustibles gasesos and II-UNAM in 2018 in the publication "Feedstock database for biogas in Mexico".

Table 33. Nitrogen recycle calculations

	Nitrogen concentration	Nitrogen load
	kg/tonTS	tonN/year
NORSON		
Fats (screen)	33	2.78
Semi-dry DAF sludge	33	5.63
PEGSON		
Stomach/ Intestine content	60	10.37
Flotation fat	33	0.79
Residue blood	0.25	0.00
Manure (corrals)	10.1	0.48
ILLIS		
DAF sludge	33	0.60
LIQUID RESIDUES HANDLED BY AGUA DE HERMOSILLO		
Grease tramps	33	16.57
FEEDSTOCK FOR CO-DIGESTION	**36.4**	**37.2**

N content in urea		**0.47**	**kgN/kg_urea**
Urea molecule equivalent		37	tons/year
% purity fertilizer		44%	
Urea fertilizer equivalent		84	tons/year
Cost of urea fertilizer		7000	MX$/ton
Price equivalence	$	30 852	USD$/year

3.3.9. Conclusions and recommendations

3.3.9.1. Key figures

For co-digestion system at Hermosillo WWTP:

- ○ The investment cost is approximately USD 588 176
- ○ The payback period is between 3.6 and 4.8 years, depending on the valorization of the sludge.
- ○ Additional electricity production is approximately 187 kW.
- ○ The GHG reduction is 6 751 ton$_{CO2}$/year.

- The nitrogen recycle as nutrient is 37.2 ton$_N$/year.

3.3.9.2. SWOT analysis

Strengths **What are the main reasons for choosing this site?**	Weaknesses **What are the main reasons for not choosing this?**
- Easy to use biogas on site: biogas and CHP facilities already exists and are overdesigned. - Norson, PECSON, ILIS and other factories are already spending money for transportation and disposal of their residues. - Norson and other industries seems aware and willing to change their residues handling if this change means saving costs and/or a positive image for the company. - Collateral benefits (reuse of nutrients and reduction of GHG) are significant. - Agricultural areas nearby for treated wastewater and digestate reuse.	- No other example of co-digestion in Mexico, no experience with this kind of facilities.
Opportunities How can strengths be used and weaknesses be overcomed?	**Threats** What are the main risks related to a project at this site?
- Denmark has a lot of experience regarding co-digestion that could be shared with the stakeholders of this project. - Potential cost reduction of water fee due to less operations costs regarding water treatment.	- No local technical support for the rotor cutter, pumps and other special equipment required for the project. - The feasibility of this project completely depends on the operation of CHPs, which would not be possible if Hermosillo WWTP does not solve the biogas desulphurization issue. - The feasibility of this project strongly depends on the valorization of the sludge and the negotiations between Hermosillo WWTP and farmers.

Table 33. SWOT Analysis

3.3.9.3. Lessons learned

- **GOVERNMENTAL SUPPORT/ PRIVATE INVESTMENT.** Due to the involvement of different sectors in a co-digestion project (industries, WWTP, farmers, etc), it is necessary that this kind of projects be strongly promoted by the government (public sector). Nevertheless, it seems convenient in terms of technical capacity, time and risks that the investment costs and operation of a co-digestion project involves a private operator.
- **NEGOTIATION**. Co-digestion projects require to ensure the involvement of several stakeholders that complies with the quality of the residues requested for the co-digestion. Negotiation and clear agreements between them are crucial for a long-term success.
- **VALORIZATION OF SLUDGE**. Recycle of nutrients from WWTP sludge is important in terms of environment but also from the economic side of a residue valorization project.

3.3.9.4. Following steps

- Revision of the industrial residues that are currently disposed to TECMED in order to find potential feedstocks.
- Sensibilization of this project with different stakeholders, joint analysis about the logistics of transportation and reception of solids in the plant.
- Characterization of the potential feedstocks and (if necessary) treatability tests.
- Confirmation of the maximum capacity in the WWTP for mixing and biogas handling.
- Promote a future biogas desulphurization project at the WWTP, preferably a biological system.
- Revision of the transportation costs for the co-digestion scenario in order to confirm and detail the business model.
- Negotiation for the reuse of sludge in agricultural lands. Confirmation of the location and the quality of sludge is required (Class A, B or C).
- Confirmation of the need of pasteurization or hygienization step in order to meet the sludge quality required by farmers.
- Confirmation of the need of a premix and/or an odour treatment system.

4. Summary

Table 34 shows the main results of the prefeasibility studies carried out in Sonora. The most promising project is the co-digestion at Hermosillo WWTP. It is strongly recommendable to carry-out a further detailed technical-economical analysis.

The second most promising project is the anaerobic lagoons at pig farms, due to the collateral benefits and replicability. It is important to remind that the payback period of the anaerobic lagoon could improve in a further detailed economic analysis if the current expenses in the large sedimentation ponds are deducted from the investment costs of this project and the replacement of diesel was taken into account.

The third most promising project is the UASB at Norson slaughterhouse. This project may also have a better payback time if the analysis of saving costs of chemicals at the existing DAF is considered in a further detailed economic evaluation. The replicability of anaerobic reactors and biogas use on-site at the industries is also a valuable contribution. Nevertheless, the collateral benefits of this project under the circumstances in Hermosillo are low.

Table 34. Results of pre-feasibility studies in Sonora

	Investment cost	Payback time	GEI reductions	N recycling
	USD$	year	Ton CO_2/year	Ton N/year
Lagoon at pigfarm (only anaerobic and biogas)	637 381	6.7	8 870	158
UASB at Norson	882 391	8	703	4
Co-digestion with recycling of N	588 176	3.6-4.8	6 751	37

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ANNEX 1 – MEXICAN NORMATIVITY REGARDING WASTEWATER AND SLUDGE

WASTEWATER FOR IRRIGATION

The most updated version of this official norm is the project of norm **PROY-NOM-001-SEMARNAT-2017**, which would be implemented soon in Mexico. This norm establishes the maximum permissible limits of pollutants in wastewater discharges into national waters bodies. According to this standard, the most important limits to comply are:

		Monthly average	Daily average	Instantaneous value
Temperature	°C	35	35	35
Fats and oils	mg/L	15	18	21
TSS	mg/L	100	120	140
COD	mg/L	150	180	210
COT	mg/L	38	45	53
Total nitrogen	mg/L	NA	NA	NA
Total phosphorus	mg/L	NA	NA	NA
Helminth eggs	eggs/L	1	1	1
Escherichia coli	MPN/100mL	1 000	1 200	1 400
pH		6.5-8.5	6.5-8.5	6.5-8.5
True color		Purity 50%	Purity 50%	Purity 50%
Acute toxicity	(UT)	<=5	<=5	<=5
Arsenic	mg/L	0	0.3	0.4
Cadmium	mg/L	0.2	0.3	0.4
Cyanide	mg/L	1	2	3
Chromium	mg/L	1	1.25	1.5
Mercury	mg/L	0.01	0.015	0.02
NIquel	mg/L	2	3	4
Lead	mg/L	0.2	0.3	0.4
Zinc	mg/L	10	15	20

WASTEWATER FOR DISCHARGING INTO THE MUNICIPAL SEWERAGE

The **NOM-002-SEMARNAT-1996** establishes the maximum permissible limits of pollutants of wastewater discharges into urban or municipal sewage. The most important limits specified are:

		Monthly average	Daily average
Temperature	°C	<40	<40
Fats and oils	mg/L	50	75
TSS	mg/L	150	200
BOD	mg/L	150	200
pH		10-5.5	10-5.5
Floating matter		Absence	Absence
Total Arsenic	mg/L	0.5	0.75
Total Cadmium	mg/L	0.5	0.75
Total Cyanide	mg/L	1	1.5
Total Copper	mg/L	10	15
Total Chromium	mg/L	0.5	0.75

Total Mercury	mg/L	0.01	0.015
Total Niquel	mg/L	4	6
Total Lead	mg/L	1	1.5
Total Zinc	mg/L	6	9

SLUDGE

The **NOM-004-SEMARNAT-2002** specifies the maximum permissible limits of pollutants in the sludge and biosolids in order to be used for soil improvement. According to this norm, the biosolids should comply with the following parameters depending on the quality of sludge (A, B, or C):

Table. Classes of sludge (NOM-004-SEMARNAT-2002)

TYPE	CLASS	USE
EXCELLENT	A	Public uses with directly contact Uses for classes B & C
EXCELLENT OR GOOD	B	Public uses without directly contact Uses for class C
EXCELLENT OR GOOD	**C**	**Forest, agricultural uses and for soil improvement (fertilizer)**

Table. Biosolids parameter (NOM-004-SEMARNAT-2002)

Class	Bacteriologic indicator	Pathogens	Parasites
	Faecal coliforms (MPN/g dry weight)	**Salmonella spp. (MPN/g dry weight)**	**Helminth eggs/ g dry weight**
A	< 1 000	< 3	< 1 (viable)
B	< 1 000	< 3	< 10
C	< 2 000 000	< 300	< 35

Table. Metals limits in biosolids according to NOM-004-SEMARNAT-2002

Metal	Excellent	Good
	mg/kg (dry weight)	**mg/kg (dry weight)**
Arsenic	41	75
Cadmium	39	85
Chromium	1 200	3 000
Copper	1 500	4 300
Lead	300	840
Mercury	17	57
Nickel	420	420
Zinc	2 800	7 500

HELMINTH OVA (EGG) ISSUE

In 1989, the World Health Organization (WHO) drew attention to diarrhoeal diseases caused mainly by helminths present in sludge and wastewater and set guidelines for safe reuse. Helminthiases are particularly common in regions where poverty and poor sanitary conditions are dominant, like Africa, Latin-America and the Far East. Helminths are pluri-cellular worms that reproduce through ova (eggs). Helminthiases are acquired through ingestion of polluted crops or meat, and contact with faeces, wastewater or contaminated soil (Jimenez B., *et al*., 2007).

When a person ingests infectious eggs, they adhere to the duodenum where the larva leaves the shell, crossing the intestinal wall into the bloodstream. Through the blood, Ascaris (the most frequent Helminthiases) travels to the heart, lungs and bronchial tubes where it breaks the walls, remaining around 10 days in the alveolus. Then it travels to the trachea from where it is ingested, again returning to the intestine, where it reaches its adult phase and, once mated, the female produces up to 200 000 eggs per day. During its migration Ascaris may cause fever, urticaria and asthma; it may encyst in kidney, bladder, appendix, pancreas or liver, and its presence in the intestine produces abdominal pain, meteorism, nausea, vomiting, diarrhoea and undernourishment. In general, the infective agents are the eggs, not the worms. Worms cannot live in wastewater or sludge because they need a host. Therefore, part of the control strategy for helminthiasis is to remove the eggs from wastewater and inactivate them in the sludge produced from wastewater treatment. Helminth ova can remain viable in water, soil and crops for several months/years (WHO, 2006).

Not all wastewater and sludge contain significant amounts of helminth ova. For this reason, they are not included in all countries' wastewater regulations or in all sludge revalorisation options. Regarding pig slurry, helminth eggs can be somewhat controlled by hygienic measure, but parasites may be still present in indoor intensive pig operations (Belœil, PA., et al., 2003).

ANNEX 2 – ELECTRIC TARIFF SCHEME IN MEXICO

In March of last year, the new tariff scheme of the Federal Electricity Commission (CFE) came into force. Since the introduction of the energy reform, the Energy Regulatory Commission (CRE) oversees the definition of electricity rates, a task that was previously carried out by the CFE.

The purpose of the new tariff scheme is to promote the efficient development of the electricity industry, in which prices are based on the costs of production and distribution of electric service. To the above, the costs of fossil fuels used to generate electricity are added, it should be noted that these costs vary month by month.

With this scheme, the electricity receipts break down the price into: transmission, distribution, CENACE (National Center for Energy Control) operation, basic supply operation, related services not included in the MEM (Wholesale Electricity Market), generation costs and capacity. The structure was changed in view of the fact that in the future there will be energy generating companies that will sell energy.

The users were grouped according to their consumption characteristics, the voltage level to which they are connected and the type of measurement they have. In this way, the following twelve rate categories are established and their correspondences to the previous rate are also presented:

Table. Rate categories

Rate category:	Description	Previous rate
DB1	Domestic Low Voltage, consuming up to 150 kWh/month.	1, 1A, 1B, 1C, 1D, 1E, 1F
DB2	Domestic Low Voltage, consuming more than 150 kWh/month.	1, 1A, 1B, 1C, 1D, 1E, 1F, DAC
PDBT	Small Demand (up to 25 kW/month) in Low Voltage.	2,6
GDBT	Great Demand (greater than 25 kWh/month) in Low Voltage.	3,6
RABT	Agricultural irrigation in Low Voltage.	9, 9CU, 9N
APBT	Public Lighting in Low Voltage.	5, 5A
APMT	Public Lighting in Medium Voltage	5, 5A
GDMTH	Great Demand (greater than 25 kWh-month) in Horary Medium Voltage.	HM, HMC, 6
GDMTO	Great Demand (greater than 25 kWh-month) in Ordinary Medium Voltage.	OM, 6
RAMT	Agricultural Irrigation in Medium Voltage.	9M, 9CU, 9N
DIST	Industrial Demand in Sub transmission.	HS, HSL
DIT	Industrial Demand in Transmission.	HT, HTL

In each rate category, fixed (per user) and variable (capacity and generation) charges are defined, which reflect the cost nature in each component of the Basic Supply Final Rates (TFSB) and are adapted to the characteristics of consumption and measurement of each user.

Final rate components of the basic supply are:

Supply charge: Fixed charge, independent of the amount of consumption or demand of the user.

Distribution: Cost for distributing electricity through the CFE infrastructure. The distribution rates apply only to users in medium and low voltage, based on the following:

a) For the APBT and RABT rate categories, the charge indicated for the PDBT category will be applied.

b) For the GDMTH, GDMTO, APMT and RAMT rate categories the designated charge for the GDMT category will apply.

Transmission: Charge for the conduction of electrical energy from the generation plants to the delivery point for distribution. The transmission charges are applied per kWh corresponding to the loads and are determined by the voltage level:

a) Categories DB1, DB2, PDBT, GDBT, APBT, RABT, APMT, RAMT, GDMTO, GDMTH and DIST cover the amount corresponding to the voltage level below 220 kV.
b) The DIT category covers the amount for voltages greater than or equal to 220 kV.

CENACE: Charge performed by the National Center for Energy Control (CENACE). The operating charge of CENACE is applied in all rate categories, through an amount per level of consumption (kWh) corresponding to the charges.

Generation: It consists of an energy charge and a capacity charge:

I. **Energy**: It is established by a single variable amount for those categories with simple measurement and with charges for the base, intermediate, peak and semi-peak horary periods corresponding to each rate division, for the categories with hourly measurements.
    a. Categories with unique charge for energy: DB1, DB2, PDBT, GDBT, RABT, RAMT, GDMTO, APBT and APMT.
    b. Categories with charge for hourly energy: GDMTH, DIST and DIT.
II. **Capacity**: They are applied based on the following:
    a. Categories with charge assigned to consumption (kWh): DB1, DB2, PDBT, APBT, APMT and RABT.
    b. Categories with charge assigned to the maximum demand (kW): GDBT, GDMTO and RAMT.
    c. Categories with charge assigned to the maximum demand coinciding with the peak hour period (kW).

SCnMEM: Corresponds to other costs related to the Wholesale Electricity Market. The charge for Related Services not included in the MEM is 0.0054 pesos/kWh and will be applicable for the 12 rate categories and 17 rate divisions. Once the corresponding rate regulation has been established, the charge must refer to the document issued for that purpose.

PARAMETERS

i. Horary periods
ii. Load factors
iii. Loss factors

Horary periods:

a) The base, intermediate, peak and semi-peak horary periods are established in the categories with hourly measurements, in order to perform a differentiated charge according to the period in which the cost of generation is higher.
b) The horary periods are assigned in each of the three systems: Baja California Interconnected System (BC), Baja California Sur Interconnected System (BCS) and National Interconnected System (SIN).
c) In the BC ad BCS systems, the rate divisions of the same name will correspond to each one of them; in the SIN system the rest of the divisions will correspond.
d) The seasons of the year in each of the systems for which the horary periods are defined, will be as follows:

Table. Seasons of the year.

System	Rate category	Season	Period
Baja California	GDMTH, DIST and DIT	Summer	From May 1 to Saturday before the last Sunday of October.
		Winter	From the last Sunday of October to April 30.
Baja California Sur	GDMTH, DIST and DIT	Summer	From the first Sunday of April to the Saturday before the last Sunday of October.
		Winter	From the last Sunday of October to the Saturday before the first Sunday of April.
SIN	GDMTH	Summer	From the first Sunday of April to the Saturday before the last Sunday of October.
		Winter	From the last Sunday of October to the Saturday before the first Sunday of April.
	DIST and DIT	Spring	From the first of February to the Saturday before the first Sunday of April.
		Summer	From the first Sunday of April to July 31.
		Fall	From the first of August to the Saturday before the last Sunday of October.
		Winter	From the last Sunday of October to January 31.

e) The base, intermediate, peak, and semi-peak horary periods are defined for the BC, BCS and SIN systems according to the different times of the year, as follows (only the schedules for the GDMTH rate will be presented, since it is the most common in the industrial and commercial sectors):

Table. Category GDMTH

Interconnected System Baja California			
Summer season			
Weekday	Base	Intermediate	Peak
Monday to Friday		0:00 – 14:00 18:00 – 24:00	14:00 – 18:00
Saturday		0:00 – 24:00	

Sunday and festive		0:00 – 24:00	
Winter season			
Weekday	Base	Intermediate	Peak
Monday to Friday	0:00 – 17:00 22:00 – 24:00	17:00 – 22:00	
Saturday	0:00 – 18:00 21:00 – 24:00	18:00 – 21:00	
Sunday and festive	0:00 – 24:00		
Interconnected System Baja California Sur			
Summer season			
Weekday	Base	Intermediate	Peak
Monday to Friday		0:00 – 12:00 22:00 – 24:00	12:00 – 22:00
Saturday		00:00 – 19:00 22:00 – 24:00	19:00 – 22:00
Sunday and festive		0:00 – 24:00	
Winter season			
Weekday	Base	Intermediate	Peak
Monday to Friday	0:00 – 18.00 22:00 – 24:00	18:00 – 22:00	
Saturday	0:00 – 18:00 21:00 – 24:00	18:00 – 21:00	
Sunday and festive	0:00 – 19:00 21:00 – 24:00	19:00 – 21:00	
National Interconnected System			
Summer season			
Weekday	Base	Intermediate	Peak
Monday to Friday	0:00 – 6:00	6:00 – 20:00 22:00 – 24:00	20:00 – 22:00
Saturday	0:00 – 7:00	7:00 – 24:00 19:00 – 24:00	
Sunday and festive	0:00 – 19:00	19:00 – 24:00	
Winter season			
Weekday	Base	Intermediate	Peak
Monday to Friday	0:00 – 6:00	6:00 – 18:00 22:00 – 24:00	18:00 – 22:00
Saturday	0:00 – 8:00	8:00 – 19:00 21:00 – 24:00	19:00 – 21:00
Sunday and festive	0:00 – 18:00	18:00 – 24:00	

ANNEX 3 – REGULATIONS FOR SELLING ELECTRICITY INTO THE GRID IN MEXICO

Projected or operating biogas plants in Mexico are eligible to obtain profits from electricity generated on-site. The plant has to comply with specific regulations that depend upon the actual or projected installed capacity.

Special formalities apply for any biogas project; in Mexico, they may depend upon the federal, state of municipal (borough) jurisdiction. Prior to the Construction, the Engineering phase of the project require (under Federal State and Municipal Law):

1. Environmental Impact Assessment
2. Zoning modifications
3. Environmental Risk Assessment for the use of hazardous materials
4. Social Impact Assessment

Energy formalities are solved at the federal level, unless otherwise required by State Law.

Centralized power generation apply for any plant able to generate more than 500 kW; the electric generation permit is requested to the Mexican Energy Regulatory Commission (CRE - Comisión Reguladora de Energía), as those plants are the only that require a mandatory permit to construction, start-up, commissioning and operating as stated by the 17th Article (Artículo 17) of the Electric Industry Law ("Ley de la Industria Eléctrica," 2014). The CRE is responsible for assigning, modifying, revoking, cancelling, transferring, delaying and terminating all the permits, as stated by the 12th Article (Artículo 12) of the Electric Industry Law ("Ley de la Industria Eléctrica," 2014). The power plants participate in the Mexican Wholesale Energy Market, complying with the specific Market Rules published elsewhere.

Distributed generation apply for any plant able to generate less than 500 Kw; under this case, the plant will not require a CRE permit, but an agreement with the "provider" (Suministradores), most likely the main power broker: the Federal Electric Commission (Comisión Federal de Electricidad); the company owns a website for the registration and follow up of the distribuited generation procedure ("Plataforma informática en materia de Generación Distribuida de CFE Distribución," 2019). According to the fraction XXXVIII of the 12th article of the law ("Ley de la Industria Eléctrica," 2014) the CRE is responsible for publishing the regulations of the distributed generation, notwithstanding that the Mexican Energy Secretariat was able to publish them only for the first time ("Generación distribuida," 2017).

Both centralized and distribuited generation power plants are eligible for obtaining Clean Energy Certificates (CEL-Certificados de Energías Limpias), one per each MW generated on-site ("Certificados de Energías Limpias," 2016).

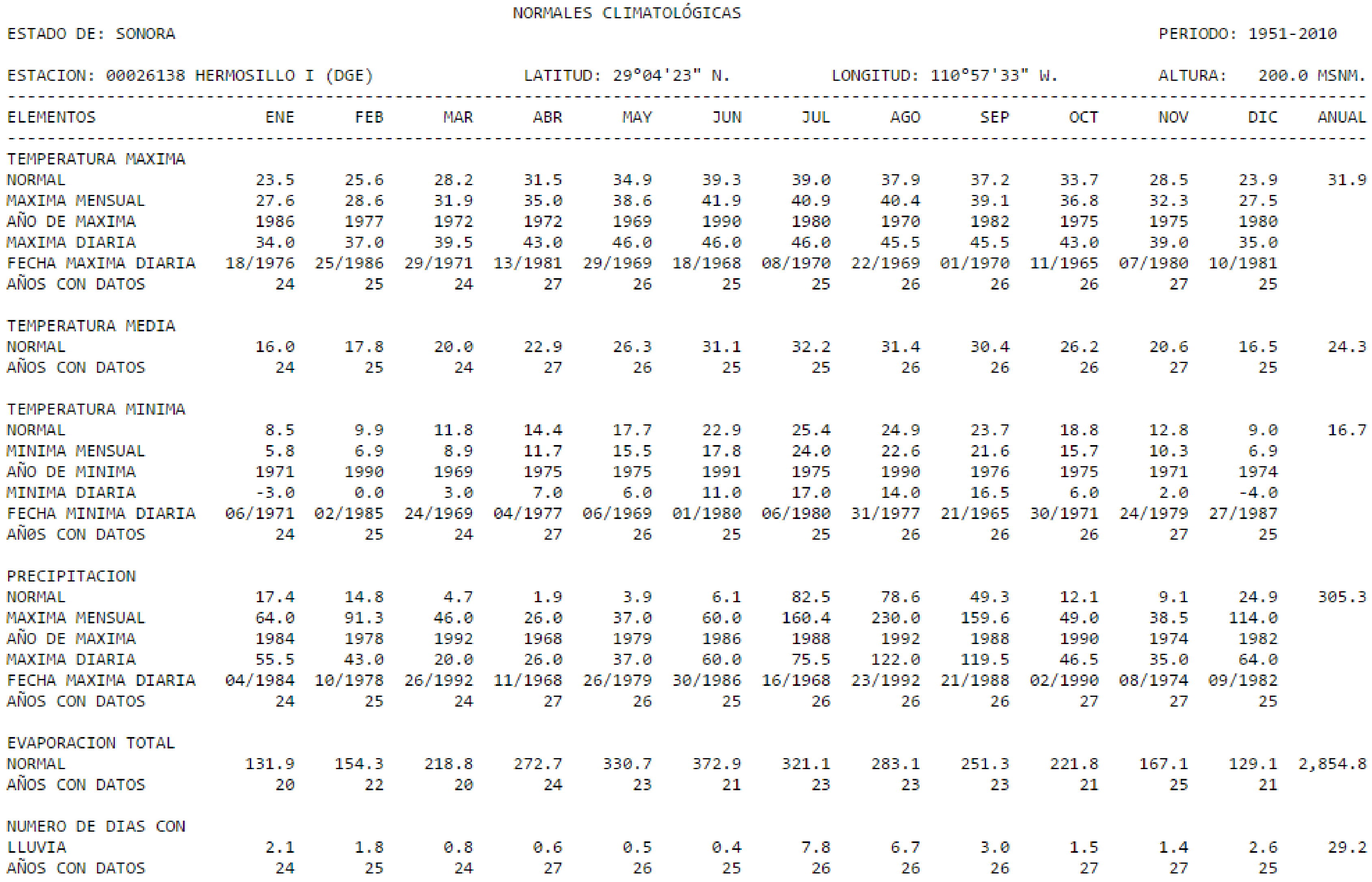
ANNEX 4 – CAPEX AND OPEX (ITEMS DEFINITIONS)

All the costs given in this document are a rough estimation for pre-feasibility study purposes. For a final investment decision, it is necessary to carry-out some basic engineering and obtain firm quotations from suppliers, manufacturers and contractors.

CAPEX	
Electromechanical equipment	It includes the supply, installation and assembly of the electromechanical equipment. The itemisation of this price is shown in each economical evaluation chapter.
Civil works and structures	It includes the concrete basement for the equipment, stairs for access and maintenance of the equipment, roofing, and others. In some cases, depending on the case, this item also includes the costs related to excavations, and machinery for soil transportation.
Electrical installation	It includes all the materials, accessories and manpower required to connect the electrical equipment to a motor control center, as well as the instrumentation signals to a control panel.
Piping and mechanical installation	It includes the materials, accessories and manpower required to do the mechanical interconnection between the electromechanical equipment installed.
Engineering project	It includes the basic and detailed engineering, the latest covers the electrical, piping, instrumentation, and civil engineering.
Start-up	It includes the expenses for specialized engineers at site and laboratory analysis required during the start-up of the system until it is stable.
OPEX	
Personnel	It includes operational and administrative staff. Depending on the anaerobic technology and size of the plant, this graph was used to estimate the personnel cost of this item: 
Laboratory	It includes routine laboratory analyses in the plant and periodic analyses in external laboratories. In all cases, it was assumed an amount of USD$50-100 per month for external laboratory analysis required to monitor the plant.
Maintenance	It includes corrective maintenance and periodic preventive maintenance. These were the percentage from the CAPEX cost assumed by experience for the annual maintenance: Building factor 0.75% Concrete tankage factor 2.00%

	Steel structures factor 1.50% Piping factor 0.50% Electrical equipment factor 2.00% Mechanical equipment factor 2.50%
Biosolids transportation	It includes transportation of treated and dehydrated biosolids to the disposal site. Depends on the case study.
Biosolids disposal	It includes the deposit at the final biosolids site. Depends on the case study.
Chemical reagents	It includes all chemical agents used in the operation of the plant. Depends on the case study.
Electrical power	It includes electrical energy for the operation of electromechanical equipment, and all relates facilities. Depends on the case study.

ANNEX 5 – CLIMATOLOGY IN HERMOSILLO, SONORA



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                                                   NORMALES CLIMATOLÓGICAS
ESTADO DE: SONORA                                                                                                   PERIODO: 1951-2010

ESTACION: 00026138 HERMOSILLO I (DGE)               LATITUD: 29°04'23" N.          LONGITUD: 110°57'33" W.          ALTURA:   200.0 MSNM.
-----------------------------------------------------------------------------------------------------------------------------------------
ELEMENTOS                 ENE      FEB      MAR      ABR      MAY      JUN      JUL      AGO      SEP      OCT      NOV      DIC    ANUAL
-----------------------------------------------------------------------------------------------------------------------------------------
TEMPERATURA MAXIMA
NORMAL                   23.5     25.6     28.2     31.5     34.9     39.3     39.0     37.9     37.2     33.7     28.5     23.9     31.9
MAXIMA MENSUAL           27.6     28.6     31.9     35.0     38.6     41.9     40.9     40.4     39.1     36.8     32.3     27.5
AÑO DE MAXIMA            1986     1977     1972     1972     1969     1990     1980     1970     1982     1975     1975     1980
MAXIMA DIARIA            34.0     37.0     39.5     43.0     46.0     46.0     46.0     45.5     45.5     43.0     39.0     35.0
FECHA MAXIMA DIARIA   18/1976  25/1986  29/1971  13/1981  29/1969  18/1968  08/1970  22/1969  01/1970  11/1965  07/1980  10/1981
AÑOS CON DATOS             24       25       24       27       26       25       25       26       26       26       27       25

TEMPERATURA MEDIA
NORMAL                   16.0     17.8     20.0     22.9     26.3     31.1     32.2     31.4     30.4     26.2     20.6     16.5     24.3
AÑOS CON DATOS             24       25       24       27       26       25       25       26       26       26       27       25

TEMPERATURA MINIMA
NORMAL                    8.5      9.9     11.8     14.4     17.7     22.9     25.4     24.9     23.7     18.8     12.8      9.0     16.7
MINIMA MENSUAL            5.8      6.9      8.9     11.7     15.5     17.8     24.0     22.6     21.6     15.7     10.3      6.9
AÑO DE MINIMA            1971     1990     1969     1975     1975     1991     1975     1990     1976     1975     1971     1974
MINIMA DIARIA            -3.0      0.0      3.0      7.0      6.0     11.0     17.0     14.0     16.5      6.0      2.0     -4.0
FECHA MINIMA DIARIA   06/1971  02/1985  24/1969  04/1977  06/1969  01/1980  06/1980  31/1977  21/1965  30/1971  24/1979  27/1987
AÑ0S CON DATOS             24       25       24       27       26       25       25       26       26       26       27       25

PRECIPITACION
NORMAL                   17.4     14.8      4.7      1.9      3.9      6.1     82.5     78.6     49.3     12.1      9.1     24.9    305.3
MAXIMA MENSUAL           64.0     91.3     46.0     26.0     37.0     60.0    160.4    230.0    159.6     49.0     38.5    114.0
AÑO DE MAXIMA            1984     1978     1992     1968     1979     1986     1988     1992     1988     1990     1974     1982
MAXIMA DIARIA            55.5     43.0     20.0     26.0     37.0     60.0     75.5    122.0    119.5     46.5     35.0     64.0
FECHA MAXIMA DIARIA   04/1984  10/1978  26/1992  11/1968  26/1979  30/1986  16/1968  23/1992  21/1988  02/1990  08/1974  09/1982
AÑOS CON DATOS             24       25       24       27       26       25       26       26       26       27       27       25

EVAPORACION TOTAL
NORMAL                  131.9    154.3    218.8    272.7    330.7    372.9    321.1    283.1    251.3    221.8    167.1    129.1  2,854.8
AÑOS CON DATOS             20       22       20       24       23       21       23       23       23       21       25       21

NUMERO DE DIAS CON
LLUVIA                    2.1      1.8      0.8      0.6      0.5      0.4      7.8      6.7      3.0      1.5      1.4      2.6     29.2
AÑOS CON DATOS             24       25       24       27       26       25       26       26       26       27       27       25
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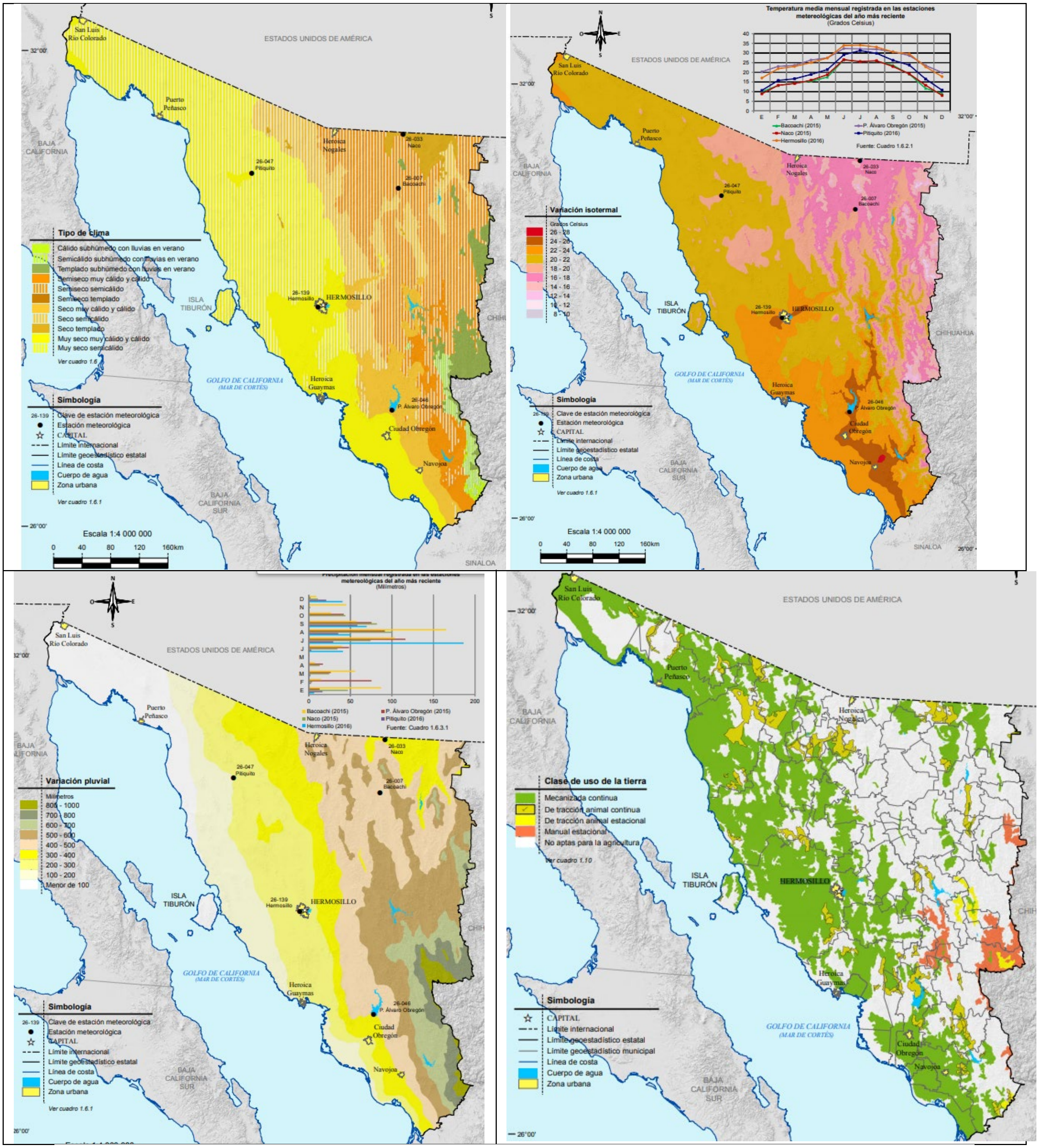


Figure. Distribution of a) Climate, b) Temperature, c) Precipitation and d) Crop potential (INEGI, 2017)

ANNEX 6 – SIZE OF DIGESTERS FOR PIG FARMS

In the pig farms of Norson, due to sanitary restrictions, it was clear that the treatment should be decentralized; it means, that each pig farm may have its own treatment system. Nevertheless, in some cases it would be a good option to transport the residues from different farms, markets and industries to the same near site in order to evaluate the size of the anaerobic system that results and the use of biogas that it may have.

According to International Renewable Resources Institute of Mexico (2015), the biodigesters are three types depending on the size:

Type of biodigesters	Size of biodigester (m^3)	Current use of biogas
Domestic sector	<25	From small scale sized (<2 Ha). Use of biogas for cooking, water heating. The digestate is often useful as fertilizer.
Productive sector	25-1000	From small and medium sized of business and family farms. Have received relatively little attention (called the "missing middle"). Biogas is useful as energy source that displaces Liquified Petroleum Gas (LPG) and electricity consumption. Possible financial savings from digestate use.
Industrial sector	>1000	For large agro-industrial livestock waste. The majority (61%) of the Industrial Sector biodigesters are not using biogas. Biogas is useful as energy source that displaces LPG and electricity consumption. Possible financial savings from digestate use.

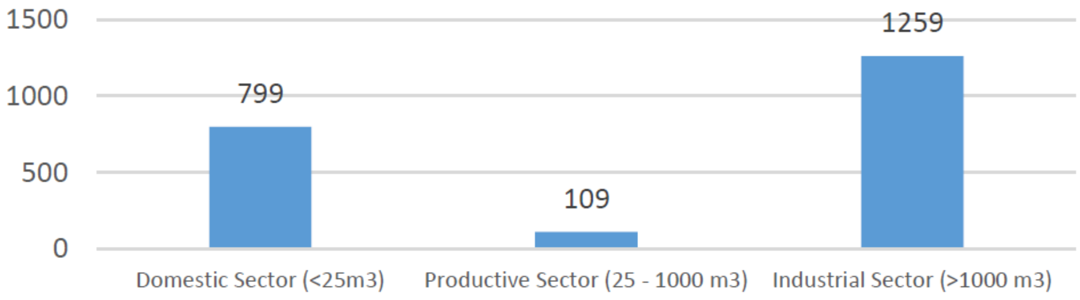


Figure. Total population of biodigesters by market sector (IRRI,2015)

For example, in order to calculate the size of the anaerobic lagoons at pig farm in Norson, it was assumed that:

- Every pig farm may have its own anaerobic pond. The option of centralized treatment of slurry at Norson pig farms was deleted due to transportation costs and sanitary restrictions.
- Slurry production in WTF is 0.313 kg of volatile solids of manure per head per day (Norson's experience)
- Slurry production in Site 3 is 0.374 kg of volatile solids of manure per head per day (Norson's experience)

- Solids concentration is 8% TS concentration; VS/TS fraction is 0.64; density is 1.04 ton/m^3.
- Anaerobic lagoons would have 35-45 days of hydraulic retention time.
- Slurry treatment would be for 42 pig farms of Norson in total, that corresponds to 7 WTF farms and 35 'Site 3 farms.

The results of the calculations of anaerobic ponds' volume require at Norson farms are shown in Figure 4.9.

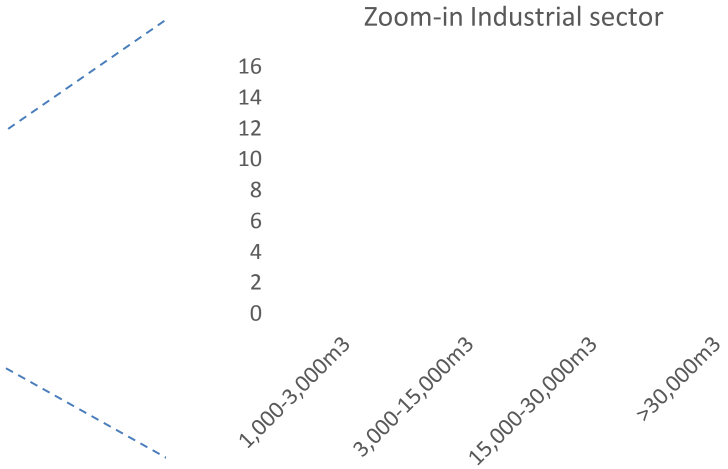


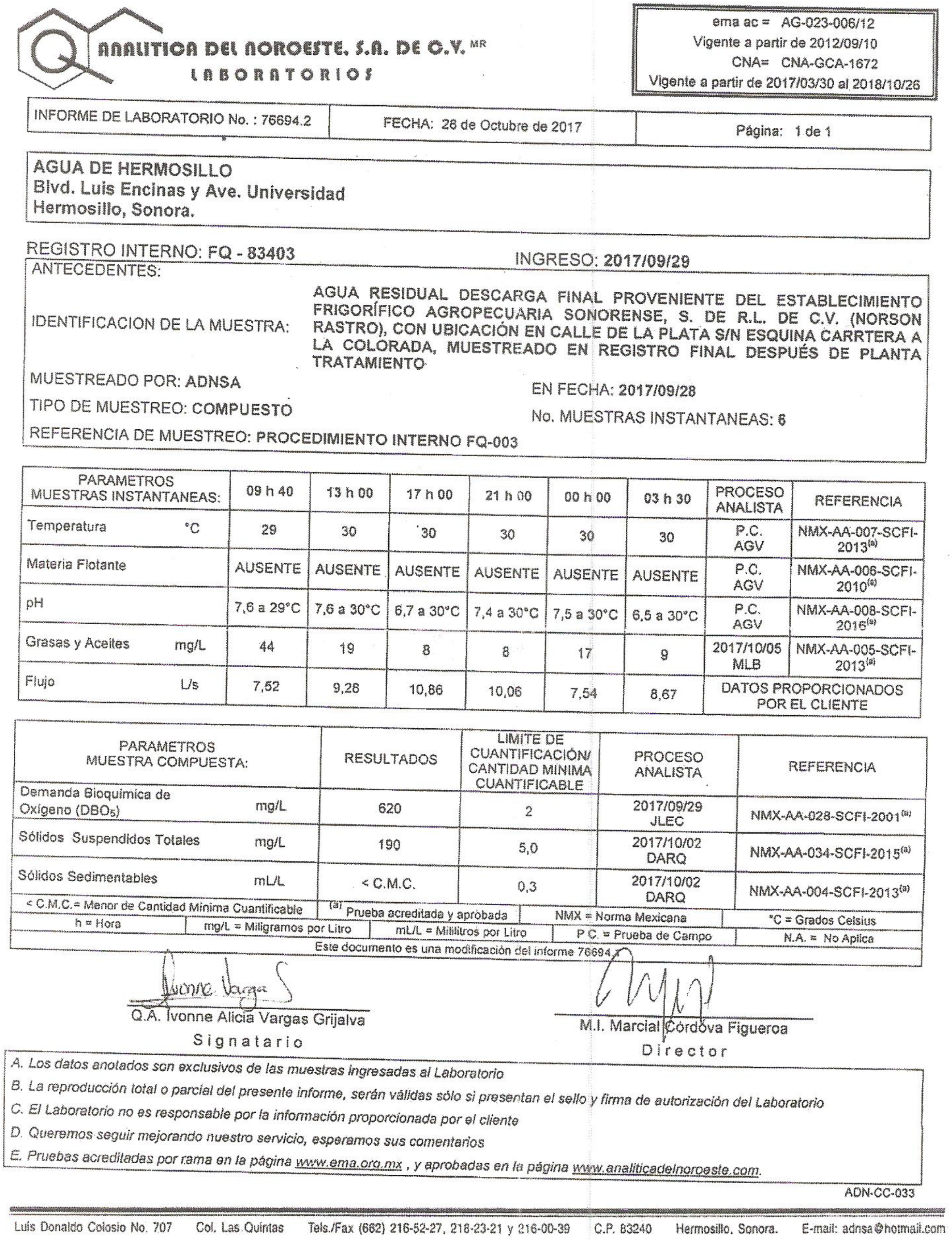
Figure . Size of potential biodigesters a Norson pig farms.

Most of Norson pig farms demand anaerobic ponds that are large enough to be considered Industrial size. 64% of the farms generate between 1 500- 3 500 kg_{VS}/d, which is equivalent to digesters generation of electricity of 64-150 kWh/h.

This result may confirm that technically and economically, a decentralized system at Norson pig farms is the most feasible option.

ANNEX 7 – CHARACTERIZATION IN NORSON

Wastewater discharge into municipal sewarage



ANALITICA DEL NOROESTE, S.A. DE C.V. MR
LABORATORIOS

ema ac = AG-023-006/12
Vigente a partir de 2012/09/10
CNA= CNA-GCA-1672
Vigente a partir de 2017/03/30 al 2018/10/26

INFORME DE LABORATORIO No. : 76694.2	FECHA: 26 de Octubre de 2017	Página: 1 de 1

AGUA DE HERMOSILLO
Blvd. Luis Encinas y Ave. Universidad
Hermosillo, Sonora.

REGISTRO INTERNO: **FQ - 83403**
INGRESO: **2017/09/29**

ANTECEDENTES:

IDENTIFICACION DE LA MUESTRA: **AGUA RESIDUAL DESCARGA FINAL PROVENIENTE DEL ESTABLECIMIENTO FRIGORÍFICO AGROPECUARIA SONORENSE, S. DE R.L. DE C.V. (NORSON RASTRO), CON UBICACIÓN EN CALLE DE LA PLATA S/N ESQUINA CARRTERA A LA COLORADA, MUESTREADO EN REGISTRO FINAL DESPUÉS DE PLANTA TRATAMIENTO**

MUESTREADO POR: **ADNSA**
EN FECHA: **2017/09/28**
TIPO DE MUESTREO: **COMPUESTO**
No. MUESTRAS INSTANTANEAS: **6**
REFERENCIA DE MUESTREO: **PROCEDIMIENTO INTERNO FQ-003**

PARAMETROS MUESTRAS INSTANTANEAS:		09 h 40	13 h 00	17 h 00	21 h 00	00 h 00	03 h 30	PROCESO ANALISTA	REFERENCIA
Temperatura	°C	29	30	30	30	30	30	P.C. AGV	NMX-AA-007-SCFI-2013(a)
Materia Flotante		AUSENTE	AUSENTE	AUSENTE	AUSENTE	AUSENTE	AUSENTE	P.C. AGV	NMX-AA-006-SCFI-2010(a)
pH		7,6 a 29°C	7,6 a 30°C	6,7 a 30°C	7,4 a 30°C	7,5 a 30°C	6,5 a 30°C	P.C. AGV	NMX-AA-008-SCFI-2016(a)
Grasas y Aceites	mg/L	44	19	8	8	17	9	2017/10/05 MLB	NMX-AA-005-SCFI-2013(a)
Flujo	L/s	7,52	9,28	10,86	10,06	7,54	8,67	DATOS PROPORCIONADOS POR EL CLIENTE	

PARAMETROS MUESTRA COMPUESTA:		RESULTADOS	LIMITE DE CUANTIFICACIÓN/ CANTIDAD MINIMA CUANTIFICABLE	PROCESO ANALISTA	REFERENCIA
Demanda Bioquimica de Oxígeno (DBO$_5$)	mg/L	620	2	2017/09/29 JLEC	NMX-AA-028-SCFI-2001(a)
Sólidos Suspendidos Totales	mg/L	190	5,0	2017/10/02 DARQ	NMX-AA-034-SCFI-2015(a)
Sólidos Sedimentables	mL/L	< C.M.C.	0,3	2017/10/02 DARQ	NMX-AA-004-SCFI-2013(a)

< C.M.C.= Menor de Cantidad Minima Cuantificable
(a) Prueba acreditada y aprobada
NMX = Norma Mexicana
°C = Grados Celsius
h = Hora
mg/L = Miligramos por Litro
mL/L = Mililitros por Litro
P C. = Prueba de Campo
N.A. = No Aplica

Este documento es una modificación del informe 76694.1

Ivonne Vargas
Q.A. Ivonne Alicia Vargas Grijalva
Signatario

M.I. Marcial Córdova Figueroa
Director

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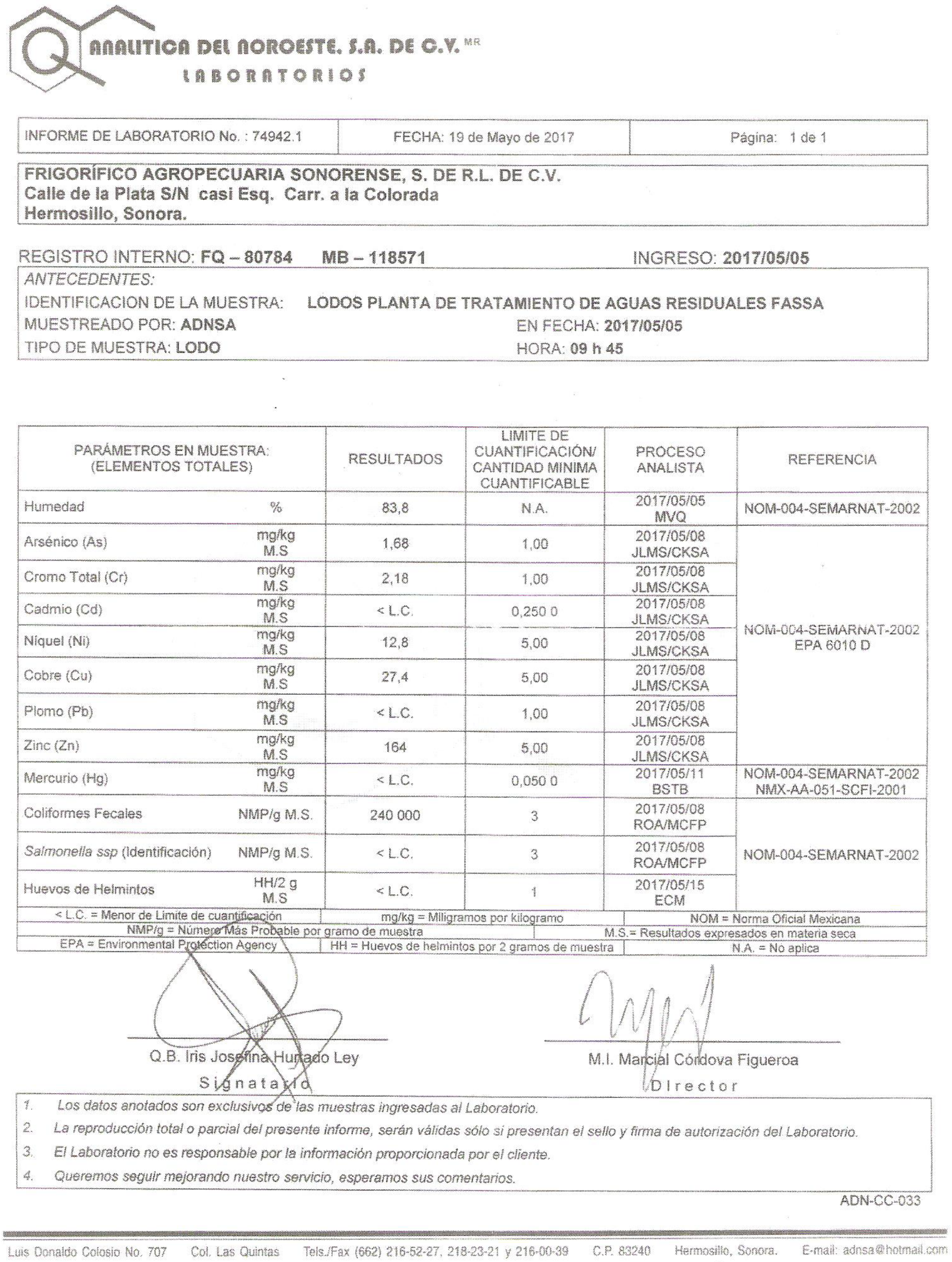
ADN-CC-033

Luis Donaldo Colosio No. 707 Col. Las Quintas Tels./Fax (662) 216-52-27, 218-23-21 y 216-00-39 C.P. 83240 Hermosillo, Sonora. E-mail: adnsa@hotmail.com

Sludge disposed into Tecmed Landfill



ANALITICA DEL NOROESTE, S.A. DE C.V. MR

LABORATORIOS

INFORME DE LABORATORIO No. : 74942.1	FECHA: 19 de Mayo de 2017	Página: 1 de 1

FRIGORÍFICO AGROPECUARIA SONORENSE, S. DE R.L. DE C.V.
Calle de la Plata S/N casi Esq. Carr. a la Colorada
Hermosillo, Sonora.

REGISTRO INTERNO: **FQ – 80784 MB – 118571** INGRESO: **2017/05/05**

ANTECEDENTES:

IDENTIFICACION DE LA MUESTRA: **LODOS PLANTA DE TRATAMIENTO DE AGUAS RESIDUALES FASSA**

MUESTREADO POR: **ADNSA** EN FECHA: **2017/05/05**

TIPO DE MUESTRA: **LODO** HORA: **09 h 45**

PARÁMETROS EN MUESTRA: (ELEMENTOS TOTALES)		RESULTADOS	LIMITE DE CUANTIFICACIÓN/ CANTIDAD MINIMA CUANTIFICABLE	PROCESO ANALISTA	REFERENCIA
Humedad	%	83,8	N.A.	2017/05/05 MVQ	NOM-004-SEMARNAT-2002
Arsénico (As)	mg/kg M.S	1,68	1,00	2017/05/08 JLMS/CKSA	NOM-004-SEMARNAT-2002 EPA 6010 D
Cromo Total (Cr)	mg/kg M.S	2,18	1,00	2017/05/08 JLMS/CKSA	
Cadmio (Cd)	mg/kg M.S	< L.C.	0,250 0	2017/05/08 JLMS/CKSA	
Níquel (Ni)	mg/kg M.S	12,8	5,00	2017/05/08 JLMS/CKSA	
Cobre (Cu)	mg/kg M.S	27,4	5,00	2017/05/08 JLMS/CKSA	
Plomo (Pb)	mg/kg M.S	< L.C.	1,00	2017/05/08 JLMS/CKSA	
Zinc (Zn)	mg/kg M.S	164	5,00	2017/05/08 JLMS/CKSA	
Mercurio (Hg)	mg/kg M.S	< L.C.	0,050 0	2017/05/11 BSTB	NOM-004-SEMARNAT-2002 NMX-AA-051-SCFI-2001
Coliformes Fecales	NMP/g M.S.	240 000	3	2017/05/08 ROA/MCFP	NOM-004-SEMARNAT-2002
Salmonella ssp (Identificación)	NMP/g M.S.	< L.C.	3	2017/05/08 ROA/MCFP	
Huevos de Helmintos	HH/2 g M.S	< L.C.	1	2017/05/15 ECM	

< L.C. = Menor de Límite de cuantificación | mg/kg = Miligramos por kilogramo | NOM = Norma Oficial Mexicana
NMP/g = Número Más Probable por gramo de muestra | M.S.= Resultados expresados en materia seca
EPA = Environmental Protection Agency | HH = Huevos de helmintos por 2 gramos de muestra | N.A. = No aplica

Q.B. Iris Josefina Hurtado Ley
Signatario

M.I. Marcial Córdova Figueroa
Director

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